

Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas

Quarterly Technical Progress Report April 1– June 30, 2005

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Abstract

This site report document summarizes results from the project entitled “Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas” being managed by URS Group, Inc. as part of part of Cooperative Agreement DE-FC26-03NT41987. The objective of this project is to demonstrate the ability of various activated carbon sorbents to remove mercury from coal-combustion flue gas across full-scale units configured with small ESPs. The project is funded by the U.S. DOE National Energy Technology Laboratory under this Cooperative Agreement. EPRI, Southern Company, and Georgia Power are project co-funders. URS Group is the prime contractor.

Various sorbent materials were injected upstream of low SCA ESP systems at Georgia Power’s Plant Yates Unit 1 and Unit 2. Both Unit 1 and Unit 2 fire a low sulfur bituminous coal. Unit 1 is equipped with a JBR wet FGD system downstream of the ESP for SO₂ control. Unit 2 is not equipped with downstream SO₂ controls; however, a dual flue gas conditioning system is used to enhance ESP performance. This site report focuses on the result from the Unit 1 test program. A separate site report will be issued for Unit 2.

Short-term parametric tests were conducted on Unit 1 to evaluate the mercury removal performance of activated carbon sorbents. Based on the results from these parametric tests, a continuous month-long carbon injection test was performed with RWE Rheinbraun’s Super HOK sorbent. The mercury removal performance and balance of plant impacts were evaluated. The results of this study provide data required for assessing the performance, long-term operational impacts, and costs of full-scale sorbent injection processes for flue gas mercury removal.

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1.0 Introduction

This Quarterly Report is submitted to the U.S. Department of Energy (DOE) as part of Cooperative Agreement DE-FC26-03NT41987, “Sorbent Injection for Small ESP Mercury Control in Low Sulfur Eastern Bituminous Coal Flue Gas”. This project evaluated full-scale sorbent injection for mercury control at two sites with low-SCA ESPs, burning low sulfur Eastern bituminous coals. Full-scale tests were performed at Georgia Power's Plant Yates Units 1 and 2 [Georgia Power is a subsidiary of The Southern Company] to evaluate sorbent injection performance. Georgia Power's Plant Yates Unit 1 has an existing low-SCA cold-side ESP followed by a Chiyoda CT-121 wet scrubber. Unit 2 is also equipped with a low-SCA ESP and a dual flue gas conditioning system. Unit 2 has no SO₂ control system.

The sorbent injection tests consisted of two phases of testing: parametric tests in which various sorbents were screened in two to three hour tests, and a month-long continuous injection test with one sorbent. The sorbent injection equipment was installed upstream of the ESP at Unit 1. Flue gas mercury concentrations were monitored at the ESP inlet, ESP outlet, and scrubber outlet. Mercury removal performance as well as balance of plant impacts were measured and analyzed.

Sorbent injection technology is targeted as the primary mercury control process on plants burning low/medium sulfur bituminous coals equipped with ESP and ESP/FGD systems. Approximately 38,000 MW of generating capacity exists for bituminous coal-fired power plants with high-efficiency particulate control devices followed by wet lime/limestone FGD. In addition, about 70% of the ESPs used in the utility industry have SCAs less than 300 ft²/1000 acfm. Full-scale testing of sorbent injection systems on ESP systems has shown promising results; however, all previous tests have been conducted for large-SCA ESP systems. Therefore, the data from this sorbent injection project are applicable to a large portion of the market and fill a data gap for the application of sorbent injection to low-SCA ESP systems.

The project team includes URS Group, Inc. as the prime contractor. EPRI, a team member and a major co-funder of the project, has funded and managed mercury emissions measurement and control research since the late 1980's. ADA-ES was a sub-contractor to URS and was responsible for all aspects of the sorbent injection system design, installation and operation. Southern Company and Georgia Power were team members and provided co-funding, technical input, and the host sites for testing.

Field testing was completed in previous quarters. During this past quarter, further analysis of field data and field samples was conducted. This analysis includes ESP arcing and particulate breakthrough during the long-term injection test. An economic analysis was conducted, and is currently under review by team members. It will be reported in the next quarterly report.

2.0 Experimental

The experimental methods and procedures used to conduct the activated carbon injection evaluation at Plant Yates are described in this section. A description of the plant, the measurement locations, and injection location is given. The carbon injection equipment used in the parametric and long-term tests is described. The executed test matrices for the parametric and long-term testing are also provided in this section.

Facility Information

Yates Unit 1 is a 100 MW (gross) Eastern bituminous coal-fired plant equipped with a cold-side ESP (SCA = 173 ft²/kafcm) for particulate control and a Chiyoda CT-121 scrubber for SO₂ control. The Chiyoda scrubber is a jet bubbling reactor (JBR) and will be referred to as the JBR or the scrubber.

Additional characteristics of Unit 1 are summarized in Table 2-1. Figure 2-1 illustrates the basic plant configuration, sorbent injection points, and flue gas sample locations for Unit 1.

Table 2-1. Yates Unit 1 Configuration

	Yates Unit 1
Boiler	
Type	CE Tangential Fired
Nameplate (MW)	100
Coal	
Type	Eastern Bituminous
Sulfur (wt %, dry)	0.8 - 1.5
Mercury (mg/kg, dry)	0.05 - 0.15
Chloride (mg/kg, dry)	100 - 600
ESP	
Type	Cold-Side
ESP Manufacturer	Buell (1971 vintage, refurbished in 1997)
Specific Collection Area (ft ² /kafcm)	173
Plate Spacing (in.)	11
Plate Height (ft)	30
Electrical Fields	4
Mechanical Fields	3
ESP Design Inlet Temp. (°F)	310
ESP Design Flow Rate (ACFM)	490,000
NO_x Controls	Low NO _x Burners
SO₂ Controls	Chiyoda CT-121 wet scrubber (JBR)
Flue Gas Conditioning	None

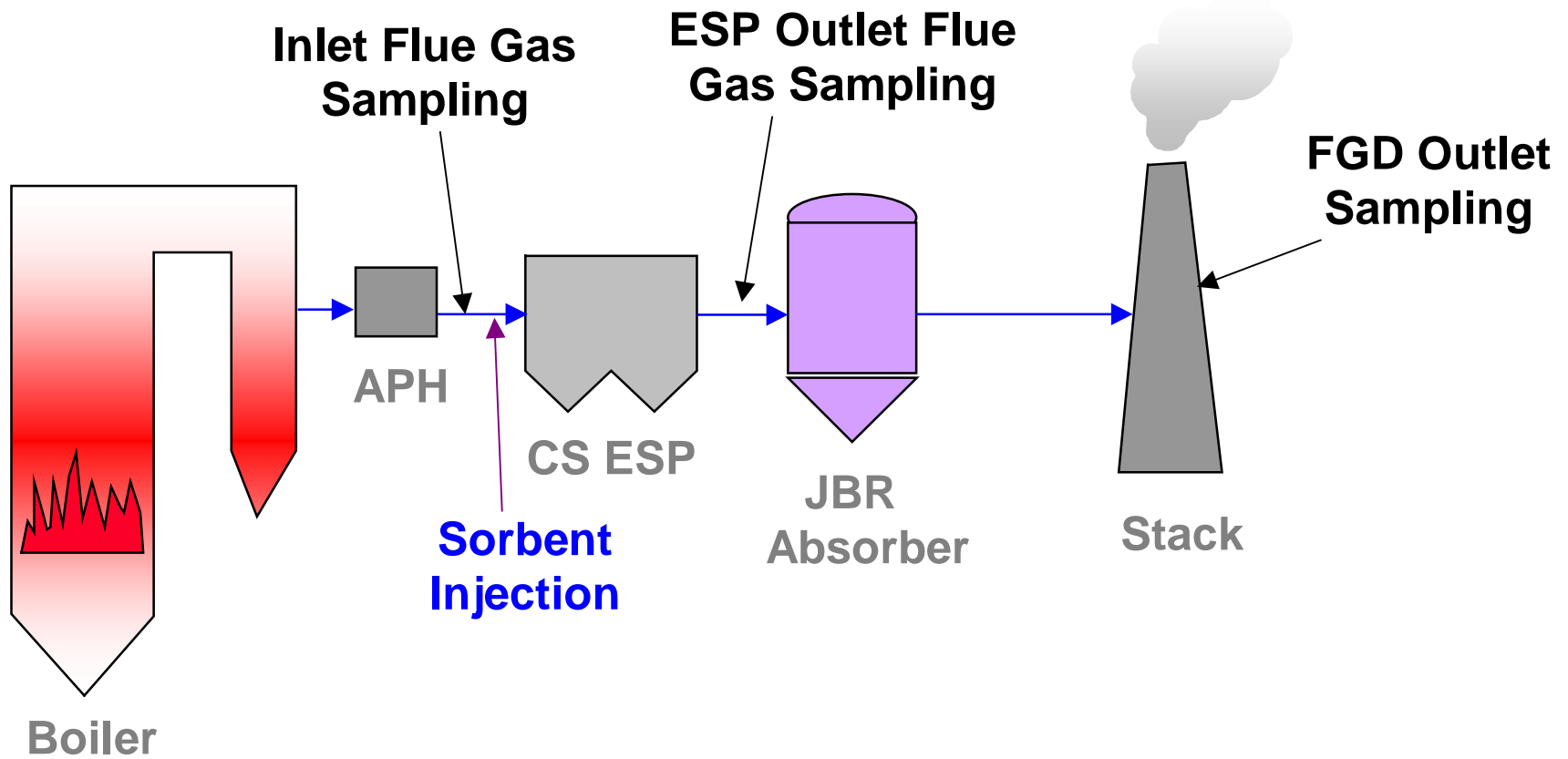


Figure 2-1. Yates Unit 1 Configuration and Flue Gas Sample Locations

Activated Carbon Injection System Design

ADA-ES, under subcontract to URS Group, provided all of the injection process equipment used during testing at Yates, installed the equipment on-site, and operated the equipment during testing.

For the short-term parametric tests conducted on Unit 1, a Port-a-Pac dosing system, supplied by Norit Americas, was used. This dry injection system, similar to the one shown in Figure 2-2, pneumatically conveys a predetermined and adjustable amount of sorbent from bulk bags into the flue gas stream. The unit consists of two eight-foot tall sections. The lower or base section consists of a small hopper with level detector, volumetric screw feeder, and pneumatic eductor. The upper or top section consists of an electric hoist and monorail to handle bulk bags of sorbent of up to 1000 pounds. When fully assembled, the system has a total height of 16-feet. Powdered activated carbon is metered using a volumetric feeder into a pneumatic eductor, where the air supplied from the regenerative blower provides the motive force needed to transport the carbon to the flue gas duct via six sorbent injection lances. The sorbent injection system can deliver approximately 20 – 350 lb/hr of activated carbon or other sorbents. The sorbent injection feed rate was verified with daily calibrations and trending of the bag emptying rate.



Figure 2-2. Port-a-Pac Dosing Unit Similar to the One used in Parametric Testing

Because of the large quantity of carbon needed for the month-long continuous injection test, a silo was used to store the carbon. The silo and feed train for the Unit 1 long-term test are pictured in Figure 2-3. The silo was 10 feet in diameter, with a sidewall height of 32 ft. The silo had a volume of 2500 ft³, and accommodated up to 60,000 lb of HOK carbon (the silo could store only 40,000 lb of Norit Darco Hg, because of the density difference between the two sorbents). The carbon injection system consisted of a bulk-storage silo and twin blower/feeder trains. Sorbent was delivered in bulk pneumatic trucks and loaded into the silo, which was equipped with a bin vent bag filter. From the two discharge legs of the silo, the sorbent was metered by variable speed screw feeders into eductors which provided the motive force to carry the sorbent to the injection point. Regenerative blowers provided the conveying air. Flexible hoses carried the sorbent from the feeders to dual distribution manifolds located on the ESP inlet duct. Each manifold supplied six injectors for a total of twelve injectors. Each of the six port flanges contained two injector lances, inserted at different lengths into the duct. The feeding system was calibrated prior to commencement of the long-term injection test. The calibration was verified throughout the injection test by means of level and weight sensors on the silo.



Figure 2-3. Carbon Injection Storage Silo/Feeder Train (Long-Term Testing)

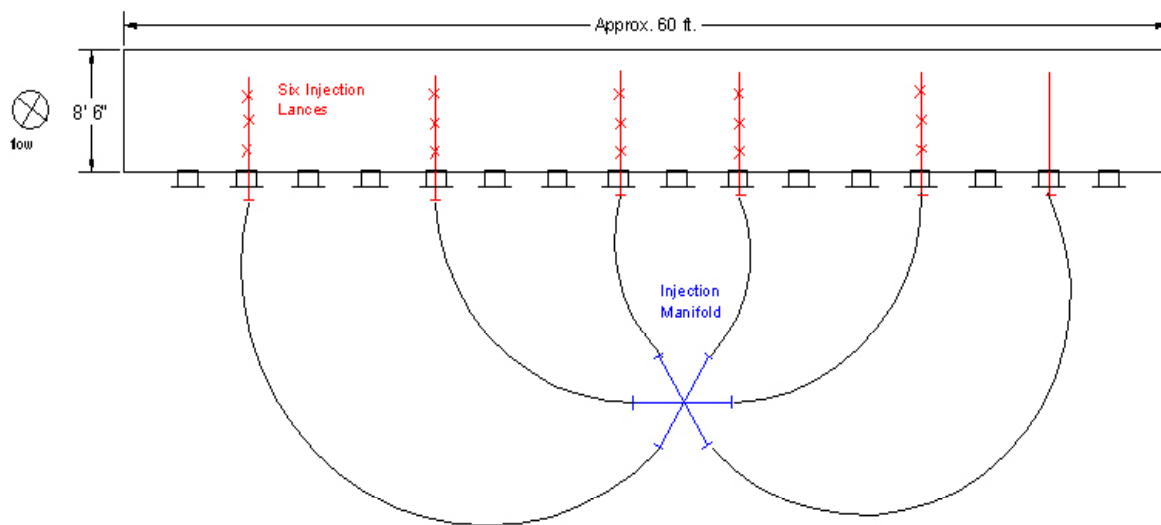


Figure 2-4. Unit 1 ESP Inlet Sorbent Injection Port Configuration During Parametric Tests (long-term tests used two lance per port)

The injection lances were fabricated from 1-inch pipe and were placed at equal spacing across the width of the duct. Figure 2-4 shows the injection lance configuration in the Unit 1 ESP inlet duct. Each lance projected horizontally into the 8.5-foot deep duct and ended approximately 4 feet into the duct. The duct is approximately 60 feet wide at this location. Each lance was open-ended with no orifices along the length of the lance. The pneumatically conveyed sorbent exited the lance end and mixed with the flue gas flowing vertically in the duct before entering the ESP.

Sorbent Selection

This section describes the properties of the sorbent materials selected for the test program. Testing was composed of two phases: (1) a parametric test program in which various sorbents were screened in two to three hour tests and (2) a long-term continuous injection program in which a single sorbent was injected into the Unit 1 ESP inlet duct for one month.

The purpose of the parametric testing was to evaluate various sorbents in order to select a single sorbent for the long-term injection test. Parametric testing consisted of evaluating the mercury removal performance of each sorbent at a range of injection rates. Three different sorbents were evaluated in initial Unit 1 parametric tests during Spring 2004. As listed in Table 22, the three carbons tested in the initial parametric tests were Norit's Darco-Hg, RWE Rheinbraun's Super HOK, and Ningxia Huahui's iodated NH Carbon.

The Darco-Hg (formerly Norit's Darco FGDTM) carbon served as the benchmark sorbent since it had been used in numerous other sorbent injection test programs and its performance characteristics were well defined. The RWE Rheinbraun Super HOK sorbent is a German lignite-derived activated carbon selected for its cost, performance in previous tests and availability in quantities necessary for this test program. The third sorbent, a Chinese iodated activated carbon, was not originally included in the test plan, but was made available at no cost to the project and tested over a two-day period on Unit 1 when the Super HOK carbon did not arrive on-site as planned. The project team made the decision to test this chemically treated activated carbon because total vapor-phase mercury removal for the Darco-Hg activated carbon showed a plateau at about 70 percent removal during tests conducted on both the Unit 1 and Unit 2 ESP earlier in March 2004. The Chinese carbon offered the potential for removals greater than 70 percent, although the cost is twice that of the benchmark Darco-Hg carbon.

Table 2-2. Sorbents Selected for Test Program

Carbon Name	Manufacturer	Description	Cost (\$/lb)
Darco-Hg (formerly Darco FGD TM)	Norit Americas	Lignite-derived activated carbon; baseline carbon (19 µm mean particle size)	0.44 ^a
Super HOK	RWE Rheinbraun	German lignite-derived activated carbon (23 µm mean particle size)	0.29 ^b
NH Carbon	Ningxia Huahui Activated Carbon Co. LTD (HHAC)	Chinese iodated bituminous-derived activated carbon (24 µm mean particle size)	0.88

a FOB Marshall, TX

b FOB east coast ports

RWE Rheinbraun's Super HOK sorbent was selected for the long-term tests on Unit 1. The sorbent was selected because of its comparable performance, its lower cost compared to Norit America's Darco Hg (formerly known as Darco FGDTM), and the paucity of "long-term" data available for sorbents other than Darco Hg.

Following the long-term injection tests, the project team decided to evaluate additional sorbents in parametric testing on Unit 1. These sorbents were selected for various reasons, including potential lower cost and the potential to overcome the plateau in removal performance seen in the Spring 2004 tests with the Darco Hg and Super HOK. The three new sorbents tested in this additional round of parametric tests are listed in Table 2-3. The sorbents were RWE Rheinbraun's coarsely ground HOK, Norit's Darco Hg-LH (a brominated carbon, formerly known as Norit E-3), and a sorbent/PRB ash mixture prepared by Southern Company. In addition, Norit's Darco Hg was tested again to compare its performance to the Spring 2004 results and to the sorbent/ash mixture.

Table 2-3. Additional Sorbents Selected for Parametric Test Program

Carbon Name	Manufacturer	Description	Cost (\$/lb)
HOK-coarse	RWE Rheinbraun	German lignite-derived activated carbon (63 μ m mean particle size)	0.265 ^a
Darco Hg-LH	Norit Americas	Brominated, lignite-derived activated carbon; (19 μ m mean particle size)	0.65 ^b
PRB/Darco Hg		Mixture that is 50/50 PRB ash from Southern Company's Miller Station and Darco Hg sorbent	0.23 ^c

a FOB east coast ports

b FOB Marshall, TX

c Estimated cost, based on raw material cost of Norit Darco Hg (\$0.44/lb) and PRB ash (\$0.0175/lb); does not include cost to mix the materials

The HOK carbon used in these parametric tests had the same composition as the carbon tested during the long-term evaluation in November/December 2004; however, for these tests the HOK carbon had a larger (coarser) particle size. RWE Rheinbraun had experience from other testing that suggested that the coarser HOK might provide nearly as good mercury removal as the finely ground HOK at a lower cost.

Testing of Norit's Darco Hg-LH at low-chloride coal sites had shown the sorbent to have higher mercury removal than untreated activated carbons. It was desired to see if a brominated carbon would have as good of a relative performance in higher chloride flue gas, such as the flue gas at Plant Yates.

The sorbent/ash mixture combined Darco-Hg with Plant Miller PRB fly ash in a 50/50 mixture. An ash/sorbent mixture has a potential cost advantage over pure activated carbon, due to the low cost of the raw ash material. Per pound of injection material, a 50/50 mixture of

carbon/ash may provide removals comparable to injection of 100% activated carbon. For example, a 50/50 carbon/ash mixture injected at 5 lb/Mmacf (that is, 2.5 lb/Mmacf activated carbon) may have the same mercury removal as injection of pure activated carbon at 5 lb/Mmacf. It is believed that the alkaline nature of the PRB ash (due to PRB's high calcium content compared to the ash formed from the bituminous coal burned at Yates) may work synergistically with the activated carbon. The 50/50 combination has been tested at Southern Company's Plant Gaston, producing mercury removals close to pure carbon material.

Test Matrix

Figure 2-1, shown previously, identifies the sampling locations for the various gaseous, streams. The type and frequency of measurements conducted at each sample location during the parametric and long-term tests are described below.

There were three distinct phases of the test program at Plant Yates Unit 1. In the first phase, baseline (no carbon injection) and first-round parametric testing were conducted in Spring 2004. Baseline (no carbon injection) tests were carried out the week of February 23rd in order to characterize Unit 1 at its normal operating conditions while under full load. Parametric tests using the Darco-Hg, Super HOK, and NH carbons were conducted the weeks of March 1st, April 6th, and March 29th, 2004, respectively. The goal of these tests was to measure the effects of sorbent injection at different addition rates.

In the second phase, one sorbent was selected for month-long testing. This testing was conducted November/December 2004. In the third phase of this test program, follow-up parametric injection tests were conducted with additional sorbents in January 2005.

Parametric Tests – Spring 2004

Table 2-4 summarizes the sample types, frequency, and analyses conducted for samples gathered for the short-term baseline and parametric tests. Three mercury SCEMs were operated continuously during the Unit 1 tests: one to service the ESP inlet, one for the ESP outlet, and one at the JBR outlet. Ontario Hydro flue gas measurements were conducted once (i.e., one set of 3 samples) during baseline. Method 26a was conducted during baseline to characterize the HCl and Cl₂ content of the flue gas. The filters collected from the Method 26a traverses were used to quantify the baseline ESP particulate emissions. Single point Method 17 measurements were taken at the ESP outlet during each parametric injection rate in order to evaluate particulate breakthrough. Single point M17 measurements were taken (rather than a full traverse) because of time limitations associated with the short-term parametric tests. Full traverses of the ESP outlet duct particulate emissions were conducted during the long-term injection tests.

Grab samples of raw coal were collected from each pulverizer feed chute after the weigh belt. Daily composite grab samples were collected during both the baseline and parametric ACI test periods. Coal samples were analyzed for mercury, chloride, and ultimate/proximate parameters. ESP fly ash samples were collected from selected fields of the ESP during the baseline and ACI tests. The field samples were composited into a single sample. ESP fly ash samples were analyzed for mercury and LOI.

Tables 2-5 through 2-8 show the sample times for each of the collected samples.

**Table 2-4. Sample Collection and Analyses for Unit 1
Short-Term Baseline and Parametric Tests (Spring 2004)**

Location	Sample Method	Parameter(s)	Frequency Per Test Condition
ESP Inlet	SCCM	Speciated Hg	Continuous
	Ontario Hydro	Speciated Hg	One Set, baseline only
	Method 26a	HCl, Cl ₂	One Set, baseline only
ESP Outlet	SCCM	Speciated Hg	Continuous
	Ontario Hydro	Speciated Hg	One Set, baseline only
	Method 26a	HCl, Cl ₂	One Set, baseline only
	Method 5	Particulate loading-traverse	One Set, baseline only
	Method 17	Particulate loading-single point	Once per injection condition
JBR Outlet	SCCM	Speciated Hg	Continuous
Coal	Grab Composite	Hg, Cl, Ult/Prox, HHV	Once per test day
ESP Fly Ash	Grab Composite	Hg, LOI	Once per test day
	Grab Composite	Waste Characterization	3 five gal. buckets, baseline only

Table 2-5. Unit 1 Baseline Test Schedule

	2/25/04						2/26/04						2/27/04					
Time	8am	10am	12pm	2pm	4pm	6pm	8am	10am	12pm	2pm	4pm	6pm	8am	10am	12pm	2pm	4pm	6pm
ESP Inlet:																		
Ontario Hydro																		
SCEM																		
M26A																		
ESP Outlet:																		
Ontario Hydro																		
SCEM																		
M26A and Loading																		
Stack Outlet:																		
SCEM																		
Coal:																		
Grab Composite																		
ESP Fly Ash:																		
Grab Composite																		
DOE Characterization																		
JBR FGD Gypsum:																		
Grab Composite																		
Makeup Water:																		
Grab Composite																		
Limestone:																		
Grab Composite																		
Bottom Ash:																		
Grab Composite																		

Table 2-6. Unit 1 Parametric Sorbent Injection Test Schedule for Darco Hg Activated Carbon

	3/1/04			3/2/04			3/3/04						3/4/04					
Test Condition	BL	SI	BL	BL	SI	BL	BL	SI	SI	SI	SI	BL	BL	SI	SI	SI	SI	BL
Begin/End Time (EST)	8:35 – 9:06	9:10 - 18:00	18:30 – 19:15	7:45 – 10:30	10:30 – 14:47	15:36 – 16:13	1:00 – 9:05	9:08 – 12:33	12:33 – 13:43	13:43 – 15:00	15:00 – 17:45	17:52 – 19:10	9:35 – 10:03	10:03 – 12:29	12:29 – 15:25	15:25 – 17:50	17:50 – 18:45	19:05 – 19:55
Injection Rate (lb/MMacf)	0	6.3	0	0	12.7	0	0	2.1	4.2	2.1	3.1	0	0	5.2	7.3	9.4	12.7	0
Injection Rate (lb/h)	0	180	0	0	365	0	0	60	120	60	90	0	0	150	210	270	365	0
ESP Inlet SCEM	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
ESP Outlet SCEM M17	C	C X	C	C	C X	C	C	C X	C X	C	C	C	C	C	C X	C X	C	C
Stack SCEM	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Coal	-	10:00, 13:05	-	9:30	13:05	-	-	9:30	13:10	-	-	-	9:10	-	13:00	-	-	-
ESP Fly Ash	-	11:00	-	-	13:30	-	-	-	13:35	-	-	-	-	-	13:00	-	-	-

C = Indicates continuous SCEM operation during test period. Other entries indicate the times (EST) that samples were collected.

BL = Baseline (no injection)

SI = Sorbent Injection

**Table 2-7. Field Test Conditions for the Unit 1
Super HOK Parametric Tests**

Date	Day 1		Day 2			
	4/6/04		4/7/04			
Injection Time Period (EST)	10:35-11:01	11:01-12:45	12:55-14:47	14:47-16:45	16:45-19:09	19:09-20:00
Actual Injection Rate (lb/MMacf)	17.0	12.9	3.3	6.0	8.8	10.2
Actual Injection Rate (lb/hr)	496	372	95	174	253	293
ESP Inlet SCEM	C	C	C	C	C	C
ESP Outlet SCEM M17	C X	C	C X	C X	C X	C
Stack SCEM	C	C	C	C	C	C
Coal	10:00	13:20	9:30, 13:30			
ESP Fly Ash		13:30	13:20			

C = Indicates continuous SCEM operation during test period. Other entries indicate the times (EST) that samples were collected.

**Table 2-8. Field Test Conditions for the Unit 1
NH Activated Carbon Parametric Tests**

Date	Day 1 3/29/04		Day 2 3/30/04	
Injection Time Period (EST)	12:02-14:10	14:10-19:02	9:00-11:05	11:05-12:45
Actual Injection Rate (lb/MMacf)	4.2	6.3	8.3	12.5
Actual Injection Rate (lb/hr)	120	180	240	360
ESP Inlet SCEM	C	C	C	C
ESP Outlet SCEM M17	C X	C X	C X	C X
Stack SCEM	C	C	C	C
Coal	9:30, 13:10		9:20	13:20
ESP Fly Ash	13:20			13:20

C = Indicates continuous SCEM operation during test period. Other entries indicate the times (EST) that samples were collected.

Parametric Tests – January 2005

Additional parametric tests were carried out during the week of January 17th, 2005. The sorbents tested in the second round of parametric tests included RWE Rheinbraun's coarse grind HOK, Norit's Darco Hg-LH (a brominated carbon, formerly known as Norit E-3), and a sorbent/PRB ash mixture prepared by Southern Company. In addition, Norit's Darco Hg was tested again to compare its performance to the Spring 2004 results and to the sorbent/ash mixture.

Tables 2-9 summarizes the sample types and frequency of collection for this second round of parametric tests and Table 2-10 shows the actual test times for the parametric tests.

**Table 2-9. Sample Collection and Analyses for Unit 1
Parametric Tests (January 2005)**

Location	Sample Method	Parameter(s)	Frequency Per Test Condition
ESP Inlet	SCEM	Speciated Hg	Continuous
ESP Outlet	SCEM	Speciated Hg	Continuous
	Method 26	HCl, Cl ₂	Once per Darco Hg-LH test condition, baseline
JBR Outlet	SCEM	Speciated Hg	Continuous
Coal	Grab Composite	Hg, Cl, Ult/Prox, HHV	Once per test day
ESP Fly Ash	Grab Composite	Hg, LOI	Once per test day

Table 2-10. Field Test Conditions for the Unit 1 Baseline and ACI Parametric Tests

	Baseline, Full Load	Coarse HOK Carbon Injection, Full Load					Darco Hg \hat{O} -Miller Ash Blend, Full Load		
	Day 1	Day 2					Day 3		
	1/17/05	1/18/05					1/19/05		
Injection Time Period (EST)	N/A	10:35 – 12:35	12:35 – 14:27	14:27 – 16:27	16:27 – 17:50	17:50 – 18:15	10:23 – 12:23	12:23 – 14:40	14:40 – 16:40
Actual Injection Rate (lb/MMacf)	0	5.0	6.9	10.4	13.9	16.2	5.0	6.9	10.4
Actual Injection Rate (lb/hr)	0	143	200	300	400	467	143	200	300

	Darco Hg-LH \hat{O} Carbon Injection, Full Load					Darco Hg \hat{O} Carbon Injection, Full Load	
	Day 4					Day 5	
	1/20/05					1/21/05	
Injection Time Period (EST)	10:20 – 12:35	12:40 – 15:15	15:15 – 16:11	16:11 – 18:30	18:30 – 20:00	10:55 – 12:55	12:55 – 18:30
Actual Injection Rate (lb/MMacf)	5.0	6.9	10.4	2.4	11.7	2.4	5.2
Actual Injection Rate (lb/hr)	143	200	300	70	337	70	150

Long-Term Test – November/December 2004

A month-long activated carbon injection test was conducted at Plant Yates Unit 1 with RWE Rheinbraun's Super HOK activated carbon. The long-term injection test started on November 15, 2004, and ended on December 14, 2004. Baseline (no injection) vapor phase mercury measurements were made during three days prior to the month-long injection test.

For the majority of the injection test, Unit 1 operated at a load set by grid demand. This load was typically 55 MW. During one week of the test, Unit 1 operated at full load (107 MW) during the 6 am – 6 pm time period, and operated at reduced load overnight. The carbon injection rate ranged from 3 to 17 lb/Macf during the month-long test, with most of the test carried out at rates between 4 and 9 lb/Macf. Carbon injection rates were selected based on vapor phase mercury removal performance and observed balance of plant impacts.

Table 2-11 summarizes the sample collections for the long-term test. Not all collected samples were analyzed for the parameters listed.

Ontario Hydro was conducted once during the week of November 30th, 2004 at the ESP outlet and JBR outlet. In previous Ontario Hydro campaigns, the evaluation points were the ESP inlet and ESP outlet. In these previous campaigns, the reactivity of the fly ash captured on the particulate filter with flue gas mercury created a bias in the partitioning of the mercury between solid and particulate phases. Furthermore, the vortex-like flow at the ESP inlet made isokinetic sampling impossible. It was decided that for the final Ontario Hydro campaign that the ESP inlet site be omitted in favor of the stack location.

Method 17 traverses were conducted at the ESP outlet during the weeks of November 30th and December 7th, 2004 in order to evaluate how load and carbon injection rate affect ESP particulate emissions.

During the long-term injection test, coal and ash samples were collected on a daily basis. The coal sample was a composite of all the mills in service. Ash samples were collected as a composite of the first two fields and a composite of the second two fields. FGD samples were collected on a semi-weekly basis.

**Table 2-11. Sample Collection and Analyses for Unit 1
Long-term Injection Test**

Location	Sample Method	Parameter(s)	Frequency of Sampling
ESP Inlet	SCEM	Speciated Hg	Continuous
ESP Outlet	SCEM	Speciated Hg	Continuous
	Ontario Hydro	Speciated Hg	One set
	Method 5	Particulate loading	One set
	Method 17	Particulate loading-traverse	
JBR Outlet	SCEM	Speciated Hg	Continuous
	Ontario Hydro	Speciated Hg	Once set
Coal	Grab Composite	Hg, Cl, Ult/Prox, HHV	Once per test day
ESP Fly Ash	Grab Composite	Hg, LOI	Once per test day
	Grab Composite	Waste Characterization	3 five gal. buckets
JBR Slurry	Grab sample	Hg, SO ₃ , SO ₄ , wt% solids	Twice weekly

Sampling and Analytical Methods

The mercury measurements for baseline and injection testing were performed with mercury semi-continuous analyzers, which are described below in more detail. During baseline testing Ontario Hydro measurements were conducted. This method is not explained further, as it is considered a standard EPA method. Coal, ash, and JBR byproduct samples were gathered regularly and analyzed by the methods described in this section.

Solid/Liquid Sampling Methods

The Unit 1 ESP consists of four electrical fields (Figure 2-5). Hoppers labeled 1-4 are under A and B fields. Hoppers labeled 5-8 are under the C and D fields. Hoppers 2, 3, 6, and 7 are the only hoppers equipped for ash sampling. Ash samples were gathered by Plant Yates personnel. The ash samples were only gathered on weekdays, because of the reduced staffing of plant personnel on weekends and holidays.

For the long-term injection test and the January 2005 parametric tests, the daily ash samples were taken as follows:

- One composite sample was taken from hoppers 2 and 3 (50% from hopper 2; 50% from hopper 3).
- One composite sample was taken from hoppers 6 and 7 (50% from hopper 6; 50% from hopper 7).

During the Spring 2004 baseline and parametric tests, ash samples were gathered as a weighted composite from the four hoppers (2, 3, 6, and 7).

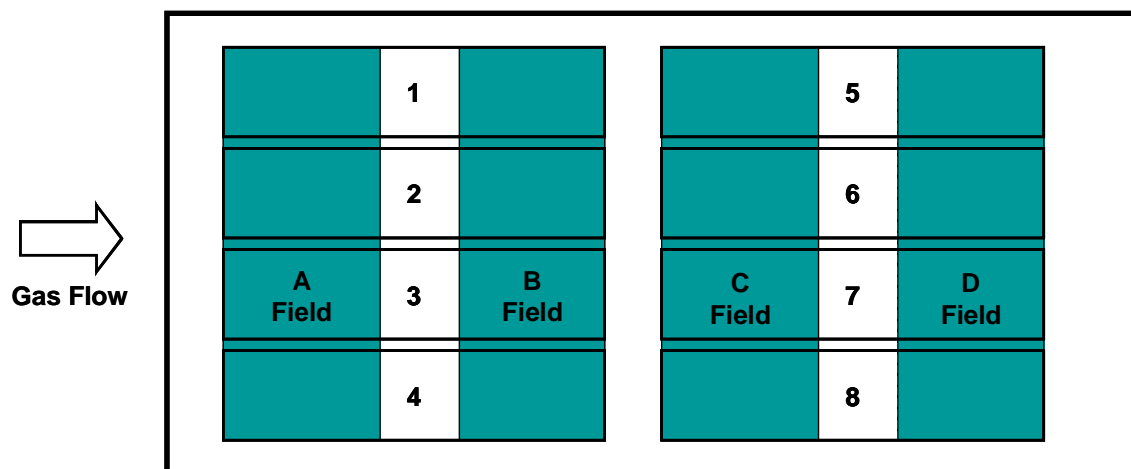


Figure 2-5. Diagram of Yates Unit 1 ESP

The Unit 1 furnace is fed with coal from four pulverizers. Coal samples were taken as a composite from the coal feeders just upstream of the pulverizers that were in service. Coal samples were gathered by both Plant Yates and URS personnel.

Approximately two times per week, URS collected FGD slurry samples for sulfite analysis and to filter for mercury solids and liquid analyses.

Solid/Liquid Analytical Methods

Solid samples, including coal and ESP hopper fly ash, were collected and analyzed for mercury content. Coal samples were also analyzed for chloride content. Coal samples were digested with ASTM 3684 and analyzed for mercury by CVAA. The coal was digested by ASTM D4208 and analyzed for chloride by ion chromatography (EPA Method 300). Ash samples and FGD solid samples were digested by a standard hydrofluoric acid digestion and analyzed for mercury by CVAA. All liquid samples were prepared by EPA Method 7470 and analyzed by CVAA. Fly ash LOI was determined by method ASTM D3174.

EPRI SCEM Mercury Analyzer

Additional details regarding the SCEM mercury analyzer are provided in this section since it is not standard EPA method. Flue gas vapor-phase mercury analyses were made using EPRI semi-continuous analyzers depicted in Figure 2-7. At each sample location, a sample of

the flue gas is extracted at a single point from the duct and then drawn through an inertial gas separation (IGS) filter to remove particulate matter. This IGS filter consists of a heated stainless steel tube lined with sintered material. A secondary sample stream is pulled across the sintered metal filter and then is directed through the mercury analyzer at a rate of approximately 1-2 L/min thus providing near real-time feedback during the various test conditions. The analyzer consists of a cold vapor atomic absorption spectrometer (CVAAS) coupled with a gold amalgamation system (Au-CVAAS). Since the Au-CVAAS measures mercury by using the distinct lines of the UV absorption characteristics of elemental mercury, the non-elemental fraction is converted to elemental mercury prior to analysis using a chilled reduction solution of acidified stannous chloride. Several impingers containing alkaline solutions are placed downstream of the reducing impingers to remove acidic components from the flue gas; elemental mercury is quantitatively transferred through these impingers.

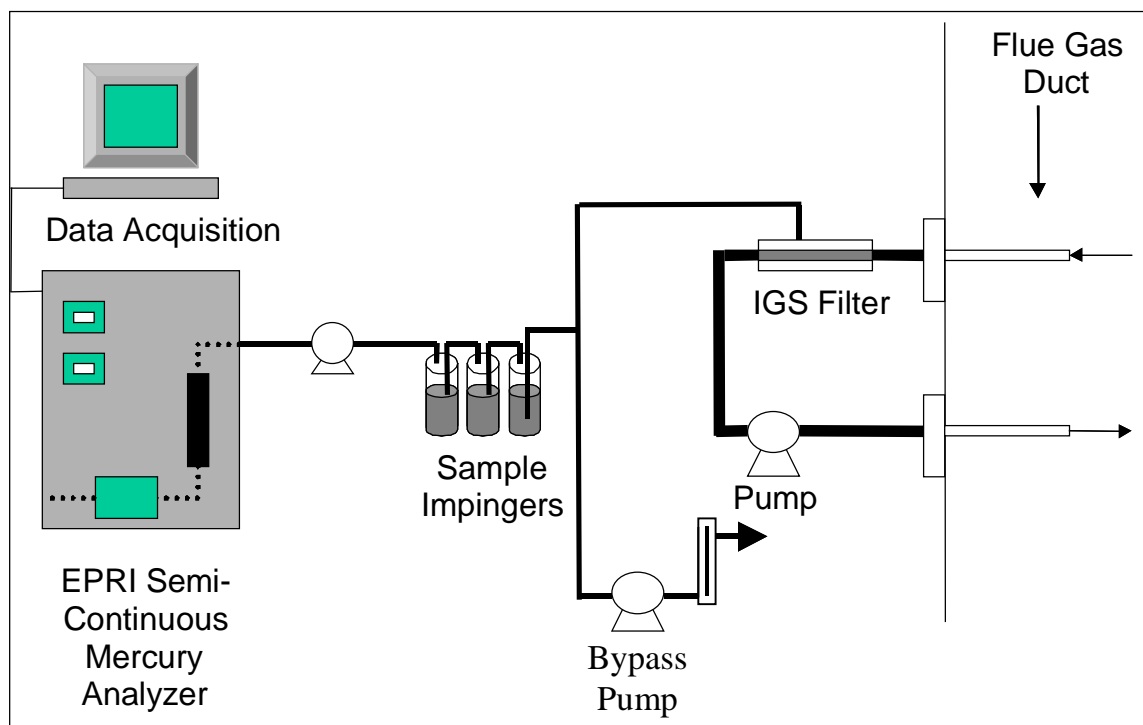


Figure 2-7. Semi-Continuous Mercury Analyzer

Gas exiting the impingers flows through a gold amalgamation column where the mercury in the gas is adsorbed ($<60^{\circ}\text{C}$). After adsorbing mercury onto the gold for a fixed period of time (typically 1 minute), the mercury concentrated on the gold is thermally desorbed ($>400^{\circ}\text{C}$) in nitrogen or air, and sent as a concentrated mercury stream to a CVAAS for analysis. Therefore,

the total flue gas mercury concentration is measured semi-continuously with a 1-minute sample time followed by a 2-minute analytical period.

To measure elemental mercury only, an impinger containing either 1M potassium chloride (KCl) or 1M Tris Hydroxymethyl (aminomethane) and EDTA is placed upstream of the alkaline solution impingers to capture oxidized mercury. Oxidized forms of mercury were subsequently captured and maintained in the KCl or Tris impingers while elemental mercury passes through to the gold amalgamation system. Comparison of “total” and “elemental” mercury measurements yields the extent of mercury oxidation in the flue gas.

3.0 Results and Discussion

The results of the sorbent injection tests from Plant Yates Unit 1 are discussed in this section. The following topics are discussed: flue gas mercury speciation and removal, coal and byproduct analyses, and impacts of sorbent injection on plant operations.

Two different metrics are used in this report to discuss the mercury removal performance of the sorbents. The first metric is the vapor phase mercury removal across a device. This metric compares the outlet vapor phase mercury concentration to the inlet vapor phase mercury concentration. The mercury removal can be calculated across the ESP, across the JBR FGD, or across the ESP/JBR system. The generic calculation for the vapor phase mercury removal is

$$\text{Percent Removal} = [1 - O/I] \times 100$$

where,

O = average SCEM total mercury concentration at the device outlet (either ESP outlet or stack) for the injection rate test period, and

I = average SCEM total mercury concentration at the inlet to the device or set of devices (either ESP inlet or ESP outlet)

The second metric used in this section is the percent reduction of vapor phase mercury at the exit of a device. Because the baseline system mercury removal was quite high, the amount of mercury reduction attributed to carbon injection was estimated by calculating the percent reduction in average total vapor-phase mercury levels at the ESP outlet and stack locations compared to average baseline levels (i.e., native levels). The percent reduction in total mercury concentration for a given injection rate is calculated as follows:

$$\text{Percent Reduction} = [1 - (O / BL)] \times 100$$

where,

O = average SCEM total mercury concentration at the ESP outlet or stack for the injection rate test period, and

BL = average SCEM total mercury concentration at the ESP outlet or stack for the baseline test period calculated based on the concentrations measured at the beginning and end of each test day.

Each datum point represents an average of the data collected over a multi-hour test period. For the parametric tests, each injection rate was tested for two to four hours. Averages of the mercury concentrations measured at each location were taken, starting from the time the

mercury concentrations at the sample locations had steadied until the injection rate was changed. These average mercury concentrations were then input into the calculations for percent mercury removal and percent mercury reduction.

3.1 Parametric Tests

Various mercury sorbents were evaluated in parametric tests. These parametric tests were conducted in two phases. The first test phase occurred in Spring 2004, and the results were used to select a sorbent for the long-term injection test. The second phase occurred in January 2005, after the long-term injection test, for evaluation of additional sorbents. This section discusses the results from the two phases of parametric tests, first presenting the mercury removal results, then discussing balance of plant impacts.

3.1.1 Plant Process Conditions

During both the Spring 2004 and January 2005 parametric tests, the unit was increased to its full-load set point of approximately 106 MW before each baseline and sorbent injection test period and held constant throughout each test. The unit load affected duct temperatures, which ultimately affected flue gas mercury concentrations and in-flight removal of mercury. In general, the temperature of the duct and mercury concentration of the flue gas increased with increasing load. The correlation between duct temperatures, load, and mercury concentration is explored in detail in the section on long-term injection results because more data were available for analysis from that test period.

3.1.2 Phase I of Parametric Testing - Spring 2004

The first phase of parametric testing on Unit 1 consisted of four weeks of testing: a baseline (no injection) test week and three weeks of sorbent testing (one week each for Darco Hg, Super HOK, and NH Carbon). The mercury removal results from these three carbons were compared in order to choose a carbon for the long-term injection test.

Baseline Characterization Tests - Mercury Removal Results

Baseline characterization of the mercury concentrations in the flue gas at the ESP inlet, ESP outlet, and stack locations were conducted over a three-day period on 2/25/04 through 2/27/04. During this period, semi-continuous data were collected for total vapor-phase mercury and elemental mercury (oxidized mercury calculated by difference) using three SCCEM analyzers. In addition, simultaneous Ontario Hydro mercury speciation measurements were conducted at the ESP inlet and ESP outlet during full-load conditions to compare to the SCCEM analyzer results.

The objectives of this series of tests were (1) to measure the native mercury concentrations at the various flue gas sample locations, and (2) to measure the variability in flue gas mercury concentrations over time.

The variability in SCEM total vapor-phase and elemental mercury concentrations at the ESP inlet, ESP outlet and stack locations during baseline test periods is shown in Figures A-1, A-2 and A-3, respectively. The variability in total vapor-phase mercury concentrations was greatest at the ESP inlet location, where total vapor-phase mercury concentrations increased from 1 to 3 $\mu\text{g}/\text{Nm}^3$ at reduced load to 4 to 7 $\mu\text{g}/\text{Nm}^3$ during full-load conditions. At the ESP outlet location at full load, the mercury concentration varied from 2 to 3.5 $\mu\text{g}/\text{Nm}^3$, with approximately 35% oxidation. At the stack at full load, the mercury concentration varied from 2 to 3 $\mu\text{g}/\text{Nm}^3$, with almost all of the vapor phase mercury present as elemental mercury. The baseline removal across the ESP was approximately 35%.

These baseline data represent only 48 hours of operation, therefore, they do not represent the range in coal compositions that the unit experiences. Throughout the rest of the test program, baseline data were intermittently gathered. In viewing all of these data together, the baseline mercury profile across the Unit 1 can vary greatly.

During the parametric injection tests, a set of baseline mercury measurements with no injection was obtained at the beginning and at the end of each sorbent injection test day. The mercury concentrations and speciation measured at the three locations were very similar to the range measured during the baseline characterization in February 2004. The mercury removal across the ESP ranged from 25-50% during these baseline periods, with only a few points outside this range. The mercury removal across the JBR saw even greater variation, with data ranging between 20 and 60% baseline removal. The mercury removal across the combined ESP/JBR system typically ranged from 60 to 75% baseline removal.

At the ESP inlet location, the percentage of the total mercury present as oxidized mercury remained essentially unchanged between daily baseline and sorbent injection tests periods, with values generally in the range of 40 to 60 percent. These values were consistent with SCEM data obtained during the baseline characterization period of 2/25/04 through 2/27/04.

Sorbent Injection Tests – Mercury Removal Results

Three sorbents were evaluated in the Spring 2004 parametric testing: Norit's Darco Hg, RWE's Super HOK, and Ningxia Huahui's activated carbon (NH carbon). The ESP inlet, outlet, and stack total vapor phase mercury measurements are shown for each day of testing of these carbons in Figures A-4 through A-11. Tables 3-1, 3-3, and 3-5 provide summaries of the average total vapor-phase mercury and mercury speciation data obtained for the sorbent injection

tests. In these tables, the oxidized mercury concentration is calculated by difference using the total and elemental mercury measurements.

Mercury removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests are tabulated in Tables 3-2, 3-4, and 3-6.

Total vapor-phase mercury removal across the ESP (i.e., ESP inlet compared to ESP outlet) is plotted as a function of sorbent injection rate in Figure 3-1 for the various sorbents. This calculation does not account for removal of particulate mercury across the ESP. Like the baseline characterization tests on 2/25/04 through 2/27/04, relatively high native removals of total vapor-phase mercury were observed without sorbent injection at the beginning and end of each sorbent injection test day. Native removal of total vapor-phase mercury across the ESP ranged from 25 to 50 percent, which probably resulted from the high carbon content (7-15 % LOI) of the ash generated by Unit 1. For all three carbons, removal across the ESP plateaued between 50 and 75% for injection rates greater than 8 lb/Mmacf (these removal percentages include baseline removal of mercury across the ESP).

Figure 3-2 shows the vapor phase mercury removal across the JBR for each of the three carbons. The Darco Hg carbon appeared to negatively impact the mercury removal across the JBR as the injection rate increased. The Super HOK carbon had only a small, but perhaps negative, impact on the mercury removal across the JBR. In contrast, the mercury removal across the JBR increased with increasing NH carbon injection rate.

Figure 3-3 shows the vapor phase mercury removal across the ESP/JBR system. The mercury removal across the ESP/JBR system plateaued between 65 and 85% at injection rates greater than 8 lb/Mmacf for all carbons.

Because the baseline mercury removal was quite high, the amount of mercury reduction attributed to carbon injection was estimated by calculating the percent reduction in average total vapor-phase mercury levels at the ESP outlet and stack locations compared to average baseline levels. Both Figures 3-4 and 3-4 show that additional mercury removal from sorbent injection plateaus around 8 lb/MMacf. For the Unit 1 ESP, Figure 3-4 indicates a 10 to 45 percent reduction in total vapor-phase mercury concentrations at the ESP outlet compared to baseline concentrations over the range of sorbent injection rates tested. At the stack, a 10 to 50 percent reduction in total vapor-phase mercury concentrations was observed compared to baseline concentrations over the range of sorbent injection rates tested.

For the three carbons, the maximum achieved percent reduction of mercury at the ESP outlet as a result of carbon injection was about 45%. The ESP mercury removal curves for the Darco Hg and the NH carbon are nearly identical, and the Super HOK curve is just slightly lower. At the stack, the NH carbon resulted in the highest combined removal across the

ESP/JBR. However, the native removal across the combined system was higher during the NH Carbon injection testing than during the other injection tests.

Figure 3-6 shows the total vapor-phase mercury emissions, expressed as lb/trillion Btu input, at the ESP outlet as a function of carbon injection rate. Without injection, the ESP outlet emissions ranged from 2.1 to 2.9 lb/trillion Btu. At an injection rate of 6 lb/Mmacf, all three sorbents were capable of bringing the Unit 1 ESP emissions below 2 lb/trillion Btu.

Table 3-1. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Darco FGD™ Activated Carbon

Date	Injection Rate (lb/MMacf)	ESP Inlet, mg/Nm ³			ESP Outlet, mg/Nm ³			Stack, mg/Nm ³		
		Total	Hg ^o	Percent Oxidized	Total	Hg ^o	Percent Oxidized	Total	Hg ^o	Percent Oxidized
3/1/04	0	7.3	2.5	66	3.8	2.3	40	1.8	1.8	1
	6.3	5.2	-	-	2.2	1.5	32	0.91	0.82	10
	0	5.2	-	-	3.8	-	-	1.2	-	-
3/2/04	0	6.9	3.6	47	3.3	2.4	25	2.5	2.3	8
	12.7	6.4	3.3	49	1.9	1.3	29	1.9	1.8	3
	0	5.9	2.8	52	3.2	-	-	2.7	-	-
3/3/04	0	7.8	3.6	54	4.3	1.9	57	2.6	2.0	23
	2.1	7.8	3.6	54	3.4	1.8	49	2.3	2.3	1
	4.2	6.9	3.3	52	2.9	-	-	2.2	-	-
	2.1	7.0	-	-		1.6	-	2.4	-	-
	3.1	7.2	3.3	55	3.1	1.5	52	1.9	2.2	0
	0	5.8	-	-	4.3	-	-	2.1	-	-
3/4/04	0	5.9	3.0	49	3.5	1.8	49	2.3	1.9	21
	5.2	6.2	3.0	51	2.4	1.3	48	1.8	1.7	2
	7.3	5.8	2.9	51	2.2	1.3	42	1.1	1.8	0
	9.4	5.5	3.1	43	2.0	1.2	40	1.6	1.7	0
	12.7	5.5	-	-	2.0	-	-	1.9	-	-
	0	5.8	3.1	46	4.0	-	-	3.1	-	-

Note: All concentrations normalized to 3% oxygen.

Table 3-2. Summary of Measured Vapor-Phase Mercury Removals for the Unit 1 ESP and JBR FGD During Injection of Darco Hg Activated Carbon

Date	Injection Rate, lb/MMacf	Removal Across ESP, %		Removal Across JBR FGD, %		Overall Removal Across ESP/JBR FGD, %	
		Total	Hg ⁰	Total	Hg ⁰	Total	Hg ⁰
3/1/04	0	48	8	53	23	75	29
	6.3	58	-	58	45	82	-
	0	26	-	68	-	76	-
3/2/04	0	53	33	24	7	64	37
	12.7	71	60	0	-36	71	45
	0	46	-	15	-	54	-
3/3/04	0	45	49	40	-7	67	45
	2.1	57	52	32	-31	70	36
	4.2	58	-	24	-	68	-
	2.1	-	-	-	-	66	-
	3.1	57	55	38	-49	73	33
	0	26	-	51	-	64	-
3/4/04	0	42	41	33	-5	61	38
	5.2	61	58	26	-37	71	42
	7.3	62	55	49	-37	81	38
	9.4	64	62	21	-43	71	45
	12.7	63	-	8	-	66	-
	0	30	-	24	-	47	-

Table 3-3. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Super HOK Carbon

Date	Rate (lb/MMacf)	ESP Inlet			ESP Outlet			Stack		
		Total Hg	Hg ⁰	% Oxidized	Total Hg	Hg ⁰	% Oxidized	Total Hg	Hg ⁰	% Oxidized
4/6/2004	0.0		2.3		3.1			2.5	2.6	-3%
	12.9	6.4	3.8	40%	2.2	0.8	62%	1.9	1.8	8%
	0.0				3.3			2.6		
4/7/2004	0.0				3.3			2.3		
	3.3	6.1			2.9			2.3		
	6.0				2.1			1.8		
	8.8	5.1			1.6	1.0	36%	1.4	1.5	-9%
	10.2	5.4			1.3			1.4		
	0.0	5.2			2.1			2.0		

Note: All concentrations are in units of $\mu\text{g}/\text{Nm}^3$ and are normalized to 3% oxygen.

Table 3-4. Summary of Measured Percent Removal of Vapor Phase Mercury Across ESP, JBR, and combined ESP/JBR During Injection of Super HOK Carbon

Date	Rate (lb/MMacf)	% Removal of Total Vapor Phase Hg		
		Across ESP	Across JBR	Across ESP/JBR
4/6/2004	0.0	51%	20%	60%
	12.9	66%	13%	70%
	0.0	48%	22%	59%
4/7/2004	0.0	47%		
	3.3	52%	21%	62%
	6.0	59%	13%	64%
	8.8	69%	9%	72%
	10.2	75%	-4%	74%
	0.0	59%	6%	61%

Table 3-5. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of NH Carbon

Date	Rate (lb/MMacf)	ESP Inlet			ESP Outlet			Stack		
		Total Hg	Hg ⁰	% Oxidized	Total Hg	Hg ⁰	% Oxidized	Total Hg	Hg ⁰	% Oxidized
3/29/2004	0.0		2.7	55%	4.1	1.9	53%	1.9	2.0	-6%
	4.2	5.9	2.4	60%	3.3			1.2		
	6.3	7.0			2.8	1.9	29%	1.1	1.2	-4%
	0.0	7.1			4.4			2.1		
3/30/2004	0.0				4.1	2.1	48%	1.9	1.6	11%
	8.3	5.5			2.7			0.9	0.9	2%
	12.5	4.9			2.4			0.7		
	0.0	4.7			4.0			1.4	1.4	2%

Note: All concentrations are in units of $\mu\text{g}/\text{Nm}^3$ and are normalized to 3% oxygen.

Table 3-6. Summary of Measured Percent Removal of Vapor Phase Mercury Across ESP, JBR, and combined ESP/HBR During Injection of NH Carbon

Date	Rate (lb/MMacf)	% Removal of Vapor Phase Hg		
		Across ESP	Across JBR	Across ESP/JBR
3/29/2004	0.0	30%	54%	68%
	4.2	44%	37%	80%
	6.3	61%	59%	84%
	0.0	38%	53%	71%
3/30/2004	0.0	25%	55%	66%
	8.3	50%	68%	84%
	12.5	51%	73%	87%
	0.0	16%	64%	70%

Balance of Plant Impacts

Because of the short-term nature of the parametric tests, only limited conclusions can be drawn about the effect of carbon injection on balance of plant operations. A more detailed analysis of balance of plant impacts is conducted with the long-term injection data, which is covered in a subsequent section of this chapter. The primary impact that sorbent injection had on the Unit 1 was related to the ESP operation.

The impact of sorbent injection on the ESP performance was quantified by taking Method 17 particulate samples at a single point in the duct during each injection rate and by monitoring the arc rate in each electrical field. The flue gas particulate concentration was measured at the ESP outlet during baseline and injection testing. During baseline testing, a Method 5 filter was used in conjunction with Method 26 traverses. During injection testing, Method 17 was employed at a single point in the duct.

Figure 3-7 shows the Unit 1 ESP outlet particulate concentrations measured during baseline and injection testing. During baseline conditions (sorbent injection rate = 0 lb/MMacf), the ESP outlet particulate concentration ranged from 0.024 to 0.052 grains/dscf at 3% O₂, with an average of 0.036 gr/dscf. For the tested carbon injection rates of 2 to 17 lb/MMacf, the measured outlet particulate concentrations were mostly within or below the range of concentrations measured during baseline testing. It should be noted that baseline measurements were taken as a traverse, while the injection test measurements are single points within the duct. Single point measurements cannot be used to quantify the emissions from the entire duct, rather they were used in this case to look at relative differences between injection rates at a common point in the duct. These measurements did not show an increase in particulate emissions with injection rate at the selected measurement point. Conversely, some of the Method 17 traverses conducted during the long-term injection test did show carbon breaking through the ESP.

Very low ESP spark rates were observed throughout the testing period. Although the spark rate remained fairly low, the arcing behavior of the Unit 1 ESP often exceeded 10 arc/minute (apm). This behavior was noted during both baseline and sorbent injection test periods, making it difficult to isolate the effect of carbon injection on the arc rate. The arcing behavior of the Unit 1 ESP caused some concern because it appeared to be influenced by sorbent injection and exceeded typical guidelines.

In the time that elapsed between the parametric tests and the long-term injection tests, the Unit 1 ESP underwent rigorous inspection and maintenance. The stand-off insulators at the bottom of the high voltage frame were found damaged or broken. It is unclear when this damage occurred (i.e. whether the damage is related to activated carbon injection). It is believed that the presence of broken insulators would lead to erratic arcing and sparking behavior in the ESP, as

was observed in the Spring 2004 testing. A visual inspection of the insulators revealed that carbon was “baked” onto the surface of the insulators. This can be clearly seen in Figure 3-8.

Prior to commencement of the long-term injection test, the insulators on the Unit 1 ESP were replaced. Replacement of the insulators provided for a baseline operation with little arcing and allowed for a clearer comparison between injection and baseline conditions. The ESP performance data from the long-term test are discussed in the section on long-term results. As will be discussed in that section, the ESP is clearly subjected to higher arcing during carbon injection at low load conditions.

Coal, Ash, and Other Process Streams

Coal

Table 3-7 shows the analytical results for as-fired coal samples. Composite samples of the Unit 1 coal were collected twice per day downstream of the coal pulverizers and were analyzed in triplicate for mercury; an average of the triplicate analyses is reported in the table. Ultimate/proximate and chlorine analyses were performed on selected samples, and these results are also shown. For the test days on which the as-fired coal was not analyzed, the proximate analyses are for the as-bunkered coal samples are given. These as-bunkered data were provided by Plant Yates.

As the coal Hg content increased, the measured vapor phase mercury at the ESP inlet increased, as shown by Figure 3-9. This plot does not account for particulate phase mercury, which could not be measured due to severe cyclonic flow at the sampling location.

Bottom Ash and Fly Ash

Table 3-8 shows the results for mercury and LOI analyses of the bottom ash and ESP fly ash samples. Composite fly ash samples were obtained by collecting and combining ash from each field of the ESP during the baseline characterization and sorbent injection test periods. A single grab sample of bottom ash was obtained. Results from baseline and the three sorbent injection test periods are shown.

There was no apparent increase in the carbon content of the ESP fly ash, as measured by percent LOI, for the activated carbon injection tests compared to the baseline tests. As shown in Figure 3-10, the mercury content of both the bottom ash and the ESP fly ash samples were directly related to the percent LOI of the ash.

Table 3-7. Unit 1 - Coal Analyses for Baseline and Carbon Injection Tests (Spring 2004)

Date	2/24	2/25	2/25	2/26	2/26	2/27	2/27	3/1	3/1	3/2	3/2	3/3	3/3	3/4	3/4
Sample Time	13:30	9:20	12:30	9:20	13:00	9:00	12:10	10:00	13:05	9:30	13:05	9:30	13:10	9:10	13:00
Test Condition ^a	BL	BL	BL	BL	BL	BL	BL	Darco-Hg	Darco-Hg	Darco-Hg	Darco-Hg	Darco-Hg	Darco-Hg	Darco-Hg	Darco-Hg
Proximate, wt % as received ^b															
Moisture	6.67	-	6.65	-	7.22	-	6.5	-	6.04	-	5.38	-	5.16	-	5.89
Ash	12.64	-	13.27	-	13.04	-	10.16	-	11.64	-	10.63	-	11.12	-	10.99
Volatile Matter	28.32	-	27.86	-	27.4	-	28.43	-	27.91	-	28.94	-	28.80	-	28.05
Fixed Carbon	52.38	-	52.23	-	52.33	-	54.90	-	54.41	-	55.05	-	54.92	-	55.07
Sulfur	0.76	-	0.73	-	0.91	-	1.29	-	0.93	-	0.95	-	0.93	-	1.16
Ultimate, wt % as received															
Moisture	-	-	3.62	-	-	-	-	-	-	-	-	-	4.40	-	-
Carbon	-	-	72.64	-	-	-	-	-	-	-	-	-	72.49	-	-
Hydrogen	-	-	4.66	-	-	-	-	-	-	-	-	-	4.69	-	-
Nitrogen	-	-	1.40	-	-	-	-	-	-	-	-	-	1.36	-	-
Sulfur	-	-	0.87	-	-	-	-	-	-	-	-	-	0.99	-	-
Oxygen	-	-	5.82	-	-	-	-	-	-	-	-	-	5.01	-	-
Ash	-	-	10.99	-	-	-	-	-	-	-	-	--	11.06	-	-
Heating Value (Btu/lb, as received)	12253 ^b	13102	12196	-	12218 ^b	-	12803 ^b	-	12651 ^b	-	12849 ^b	-	12993	-	12730 ^b
Mercury (µg/g, dry)	0.062	0.062	0.063	0.059	0.062	0.075	0.086	0.084	0.064	0.071	0.076	0.065	0.081	0.073	0.11
Mercury (lb/trillion Btu)	5.1	4.7	5.2		5.1	-	6.7	-	5.1	-	5.9	-	6.2	5.7	8.6
Chloride (mg/Kg, dry)		274	237		362	-	-	-	285	-	-	-	128	-	-

^a BL = baseline characterization, Darco-Hg = Norit's Darco HgTM carbon sorbent injection; NH = NH carbon sorbent injection; HOK = HOK sorbent injection

^b Represents Plant Yates analysis of as-bunkered fuel samples. Mercury analysis was done on separate Unit 1 as-fired coal samples.

Table 3-7, continued. Unit 1 - Coal Analyses for Baseline and Carbon (Spring 2004)

Date	3/29	3/29	3/30	3/30	4/6	4/6	4/7	4/7	4/8
Sample Time	9:30	13:10	9:20	13:20	10:00	13:20	9:30	13:30	9:30
Test Condition ^a	NH	NH	NH	NH	HOK	HOK	HOK	HOK	HOK
Proximate, wt % as received ^b									
Moisture	-	5.5	-	7.19	-	5.67	-	5.86	-
Ash	-	12.27	-	11.86	-	11.22	-	11.16	-
Volatile Matter	-	28.26	-	27.82	-	26.95	-	26.52	-
Fixed Carbon	-	53.97	-	53.14	-	56.16	-	56.45	-
Sulfur	-	0.86	-	0.86	-	0.89	-	0.89	-
Ultimate, wt % as received									
Moisture	-	-	-	5.28	-	-	-	6.21	-
Carbon	-	-	-	71.75	-	-	-	69.31	-
Hydrogen	-	-	-	4.61	-	-	-	4.36	-
Nitrogen	-	-	-	1.49	-	-	-	1.31	-
Sulfur ^b	-	-	-	1.03	-	-	-	0.93	-
Oxygen	-	-	-	4.86	-	-	-	5.68	-
Ash	-	-	-	10.98	-	-	-	12.20	-
Heating Value (Btu/lb, as received)	-	12606 ^b	-	12933	-	12789 ^b	-	12467	-
Mercury (µg/g, dry)	-	.071	-	.056	-	.086	-	.073	0.119
Mercury (lb/trillion Btu)	-	5.6	-	4.3	-	6.7	-	5.9	-
Chloride (mg/Kg, dry)	-	201	-	-	-	452	-	-	-

Table 3-8. Unit 1 – Bottom Ash and ESP Fly Ash Analyses for Baseline Characterization and Sorbent Injection (SI) Tests

Date	Time	Sample Type	Test Condition	Injection Rate (lb/MMacf)	Mercury (µg/g)	LOI (%)
2/24	13:15	ESP ash	Baseline	0	0.31	11.8
2/25	9:46	ESP ash	Baseline	0	0.26	9.9
2/25	13:10	ESP ash	Baseline	0	0.28	10.2
2/26	10:00	ESP ash	Baseline	0	0.33	12.8
2/26	13:00	Bottom Ash	Baseline	0	0.003	0.44
3/1	11:00	ESP ash	Darco FGD™ SI	6.3	0.32	12.8
3/2	13:30	ESP ash	Darco FGD™ SI	12.7	0.25	7.2
3/3	13:35	ESP ash	Darco FGD™ SI	4.2	0.27	8.5
3/4	13:30	ESP ash	Darco FGD™ SI	7.3	0.25	6.8
3/29	13:20	ESP ash	NH Carbon SI	4.2	0.182	7.97
3/30	13:20	ESP ash	NH Carbon SI	12.5	0.337	9.46
4/6	13:30	ESP ash	Super HOK SI	12.9	0.510	13.71
4/7	13:20	ESP ash	Super HOK SI	3.3	0.353	11.41

3.1.3 Phase II of Parametric Testing - January 2005

A second round of parametric carbon injection tests were conducted because several additional sorbents were identified as having promise for controlling mercury emissions. There was inadequate time to test these newly identified sorbents prior to the long-term injection test. Instead, the second round of parametric tests were conducted at the conclusion of the long-term tests, in January 2005. The results of these additional parametric tests are described in this section.

The tested sorbents included a coarse-ground HOK, a brominated activated carbon (Darco Hg-LHTM), a mixture of Darco HgTM and Miller (PRB) ash, and Darco HgTM for reference. Figures 3-11 and 3-12 show mercury removal across the ESP and ESP/JBR, respectively. Figure 3-13 shows the percent reduction in vapor phase mercury at the ESP outlet.

Unit 1 Process Operations

Unit 1 load was increased to its full-load set point of approximately 106 MW before each baseline and sorbent injection test period and held constant throughout each test. Flue gas temperatures at the air heater outlet (ESP inlet) A-side and ESP outlet, as measured by plant instrumentation, are shown in Figure 3-14. Flue gas temperatures at the ESP inlet and ESP outlet locations increased 40-50°F when Unit 1 load was increased from low load to full load. On the first three days of testing, the A-side ESP inlet temperature ranged from 260 to 275°F during the injection test period. Flue gas temperatures were about 10 to 15°F higher during the final two days (1/20/05 and 1/21/05) of full-load sorbent injection test periods compared to the earlier in the week. This can most likely be attributed to the considerably warmer weather experienced in the latter part of the testing period. A 30 to 35°F decrease in temperature was observed from the ESP inlet to the ESP outlet measurement location, presumably due to air in-leakage across the ESP and gas cooling in the approximately 50-foot run of duct between the outlet of the ESP and the outlet temperature measurement point.

Mercury Speciation and Removal Data

Sorbent Injection Tests – Coarse HOK Carbon

Table 3-9 provides a summary of the average total vapor-phase mercury concentration and mercury speciation data obtained for the Coarse HOK carbon injection test using the SCEM mercury analyzer. A set of baseline mercury measurements with no injection was obtained at the beginning of each sorbent injection test day to provide a benchmark for the sorbent injection tests. Elemental mercury measurements were obtained at the beginning and at the end of each sorbent injection test day. As a result, there are elemental mercury data that correspond with the baseline mercury measurements as well as the measurements associated with the final sorbent injection rate tested each day. Elemental mercury measurements were not obtained for every test condition because of the limited time frame in which to conduct each test.

Table 3-9. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Coarse HOK Carbon

Date	Injection Rate (lb/MMacf)	ESP Inlet, mg/Nm ³			ESP Outlet, mg/Nm ³			Stack, mg/Nm ³		
		Total	Hg ⁰	Percent Oxidized	Total	Hg ⁰	Percent Oxidized	Total	Hg ⁰	Percent Oxidized
1/18/05	0	8.6	4.9	43	4.2	2.14	50	2.8	2.2	24
	5.0	7.9	-	-	3.9	-	-	2.8	-	-
	6.9	8.5	-	-	3.7	-	-	2.7	-	-
	10.4	9.2	4.5	51	3.0	1.25	58	2.5	-	-
	13.9	10.7	-	-	2.7	-	-	-	-	-
	16.2	12.3	-	-	2.8	-	-	-	-	-

Note: All concentrations are in units of $\mu\text{g}/\text{Nm}^3$ and are normalized to 3% oxygen

Figure A-12 shows the total mercury concentrations measured at the ESP inlet, ESP outlet, and the stack, along with the Coarse HOK carbon injection rate and the unit load.

Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-9, are provided in Table 3-10. This calculation does not account for removal of particulate mercury across the ESP. Baseline removal of total vapor-phase mercury

across the ESP was 51 percent, which may be attributed to the high carbon content of the ash (13.9 percent LOI during the Coarse HOK carbon injection test period) generated by Unit 1. Removal of mercury across the ESP steadily increased to 77 percent at an injection rate of 16.2 lb/MMacf. This removal percentage includes the native removal of mercury across the ESP.

The baseline mercury removal value across the ESP/JBR FGD system was 67 percent. A slight increase in total mercury removal across the ESP/JBR FGD system was observed during the Coarse HOK activated carbon injection tests when compared to baseline. Incomplete total vapor-phase mercury data from the stack prevented calculation of an overall system removal for the two highest sorbent injection rates. According to the acquired data, total mercury removal values were increasing and had reached 73 percent at a sorbent injection rate of 10.4 lb/MMacf. This removal percentage includes the native removal of mercury across the ESP and JBR scrubber.

Table 3-10. Summary of Measured Vapor-Phase Mercury Removals for the Unit 1 ESP and JBR FGD During Injection of Coarse HOK Carbon

Date	Injection Rate (lb/MMacf)	Removal Across ESP, %	Removal Across JBR FGD, %	Overall Removal Across ESP/JBR FGD, %
1/18/05	0	51	33	67
	5.0	51	29	65
	6.9	57	27	68
	10.4	68	16	73
	13.9	74	-	-
	16.2	77	-	-

Because the native mercury removal was quite high, the amount of mercury reduction attributed to solely the Coarse HOK carbon injection was estimated by calculating the percent reduction in average total vapor-phase mercury levels at the ESP outlet location compared to average baseline levels. For the Unit 1 ESP, an 8 to 35 percent reduction in total vapor-phase mercury concentrations at the ESP outlet (compared to baseline concentrations) was observed over the range of sorbent injection rates tested.

Sorbent Injection Tests – Darco Hg⁰ Carbon-Miller Ash Blend

Table 3-11 provides a summary of the average total vapor-phase mercury concentration and mercury speciation data obtained for the Darco HgTM Carbon-Miller ash injection test using the SCEM mercury analyzer. The Darco HgTM Carbon-Miller ash blend consisted of, by weight, 50% activated carbon and 50% Plant Miller PRB ash. This blend was tested to identify if the PRB ash demonstrated a synergistic effect when combined with the activated carbon. An effective sorbent blend of ash and carbon would provide a significant reduction in sorbent cost.

With the exception of Table 2-10, in this report, the injection rate for the ash/sorbent blend is reported in terms of the lb/MMacf of carbon injected blended, which is only half the lb/MMacf of the blend. For example, if 10 lb/MMacf of the ash-sorbent blend were injected for a test, the plots and tables would list 5 lb/MMacf. This convention is used to make easier comparisons to the case where 100% Darco Hg was injected.

Table 3-11. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Darco Hg⁰ Carbon-Miller Ash

Date	Injection Rate (lb carbon/MMacf)	ESP Inlet, mg/Nm ³			ESP Outlet, mg/Nm ³			Stack, mg/Nm ³		
		Total	Hg ⁰	% Oxid.	Total	Hg ⁰	% Oxid.	Total	Hg ⁰	% Oxid.
1/19/05	0	9.5	4.0	57	3.8	1.6	59	1.8	1.7	9
	2.5	8.6	-	-	3.0	-	-	2.0	-	-
	3.5	9.0	-	-	2.8	-	-	1.9	-	-
	5.2	9.2	-	-	2.4	1.2	48	1.8	-	-

Note: All concentrations are in units of $\mu\text{g}/\text{Nm}^3$ and are normalized to 3% oxygen. Injection rate refers to the carbon-only portion of the injected blend.

Figure A-13 shows the total mercury concentrations measured at the ESP inlet, ESP outlet, and the stack, along with the Darco HgTM Carbon-Miller ash injection rate and the plant power load. Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-11, are provided in Table 3-12. Baseline removal of total vapor-phase mercury across the ESP was 60 percent. Removal of mercury across the ESP increased to 74 percent at an injection rate of 5.2 lb/MMacf of carbon.

Table 3-12. Summary of Measured Vapor-Phase Mercury Removals for the Unit 1 ESP and JBR FGD During Injection of Darco Hg⁰ Carbon-Miller Ash

Date	Injection Rate (lb carbon/MMacf)	Removal Across ESP, %	Removal Across JBR FGD, %	Overall Removal Across ESP/JBR FGD, %
1/19/05	0	60	52	81
	2.5	65	35	77
	3.5	69	30	78
	5.2	74	22	80

The baseline mercury removal across the ESP/JBR FGD system was 81 percent. There appeared to be no significant change in overall removal as a function of injection rate. For the Unit 1 ESP, a 21 to 38 percent reduction in total vapor-phase mercury concentrations at the ESP outlet (compared to baseline concentrations) was observed over the range of sorbent injection rates tested.

Sorbent Injection Tests – Darco Hg-LH⁰ Carbon

Table 3-13 provides a summary of the average total vapor-phase mercury concentration and mercury speciation data obtained for the Darco Hg-LHTM carbon injection test using the SCEM mercury analyzer. Figure A-14 shows the total mercury concentrations measured at the ESP inlet, ESP outlet, and the stack, along with the Darco Hg-LHTM carbon injection rate and the unit load.

Table 3-13. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Darco Hg-LH⁰ Carbon

Date	Injection Rate (lb/MMacf)	ESP Inlet, mg/Nm ³			ESP Outlet, mg/Nm ³			Stack, mg/Nm ³		
		Total	Hg ⁰	Percent Oxidized	Total	Hg ⁰	Percent Oxidized	Total	Hg ⁰	Percent Oxidized
1/20/05	0	11.1	5.1	54	5.0	1.8	64	2.8	2.5	8
	2.4	9.9	4.4	56	3.1	1.0	67	2.8	2.1	24
	5.0	9.7	-	-	2.7	-	-	2.5	-	-
	6.9	10.7	-	-	2.3	-	-	2.4	-	-
	10.4	9.8	-	-	1.8	-	-	1.9	-	-
	11.7	11.3	-	-	2.1	-	-	2.2	-	-

Note: All concentrations are in units of µg/Nm³ and are normalized to 3% oxygen

Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-13, are provided in Table 3-14. Baseline removal of total vapor-phase mercury across the ESP was 55 percent. Removal of mercury across the ESP appeared to plateau at 82 percent at an injection rate of 10.4 lb/MMacf.

Table 3-14. Summary of Measured Vapor-Phase Mercury Removals for the Unit 1 ESP and JBR FGD During Injection of Darco Hg-LH[®] Carbon

Date	Injection Rate (lb/MMacf)	Removal Across ESP, %	Removal Across JBR FGD, %	Overall Removal Across ESP/JBR FGD, %
1/20/05	0	55	44	75
	2.4	68	10	72
	5.0	72	6	74
	6.9	79	-4	78
	10.4	82	-4	81
	11.7	82	-8	80

The baseline mercury removal value across the ESP/JBR FGD system was 75 percent. A slight increase in total mercury removal across the ESP/JBR FGD system was observed during the Darco Hg-LH[™] carbon injection tests when compared to baseline. According to the acquired data, total mercury removal value across the ESP/JBR reached a plateau at 81 percent at a sorbent injection rate of 10.4 lb/MMacf. This removal percentage includes the native removal of mercury across the ESP. For the Unit 1 ESP, a 37 to 64 percent reduction in total vapor-phase mercury concentrations at the ESP outlet (compared to baseline concentrations) was observed over the range of sorbent injection rates tested.

Sorbent Injection Tests – Darco Hg[®] Carbon

Table 3-15 provides a summary of the average total vapor-phase mercury concentration and mercury speciation data obtained for the Darco Hg[™] carbon injection test using the SCEM mercury analyzer. Figure A-15 shows the total mercury concentrations measured at the ESP inlet, ESP outlet, and the stack, along with the Darco Hg[™] carbon injection rate and the unit load.

Table 3-15. Average SCEM Mercury Measurements for Unit 1 During Baseline and Injection of Darco Hg⁰ Carbon

Date	Injection Rate (lb/MMacf)	ESP Inlet, mg/Nm ³			ESP Outlet, mg/Nm ³			Stack, mg/Nm ³		
		Total	Hg ⁰	Percent Oxidized	Total	Hg ⁰	Percent Oxidized	Total	Hg ⁰	Percent Oxidized
1/21/05	0	10.8	-	-	6.4	1.8	72	2.2	-	-
	2.4	10.7	-	-	4.4	-	-	1.5	-	-
	5.2	11.8	-	-	3.6	-	-	1.7	-	-

Note: All concentrations are in units of µg/Nm³ and are normalized to 3% oxygen

Removal performance of the ESP, JBR FGD and combined ESP/JBR FGD controls for the various tests, calculated based on the average SCEM results from Table 3-15, are provided in Table 3-16. Baseline removal of total vapor-phase mercury across the ESP was 40 percent. Removal of mercury across the ESP increased to 69 percent at an injection rate of 5.2 lb/MMacf.

Table 3-16. Summary of Measured Vapor-Phase Mercury Removals for the Unit 1 ESP and JBR FGD During Injection of Darco Hg⁰ Carbon

Date	Injection Rate (lb/MMacf)	Removal Across ESP, %	Removal Across JBR FGD, %	Overall Removal Across ESP/JBR FGD, %
1/21/05	0	40	66	80
	2.4	59	65	86
	5.2	69	53	85

The baseline mercury removal value across the ESP/JBR FGD system was 80 percent. A slight increase in total mercury removal across the ESP/JBR FGD system was observed during the Darco HgTM carbon injection tests when compared to baseline. According to the acquired data, vapor-phase mercury removal across the ESP/JBR system reached a plateau of 86 percent at a sorbent injection rate of 2.4 lb/MMacf. For the Unit 1 ESP, a 32 to 43 percent reduction in total vapor-phase mercury concentrations at the ESP outlet (compared to baseline concentrations) was observed over the range of sorbent injection rates tested.

Comparison of Sorbent Performance

Figures 3-11 through 3-13 are composites of data presented earlier in this report. Figures 3-11 and 3-12 show the percent mercury removal across the ESP and ESP/JBR combination, respectively. Figure 3-13 shows the percent reduction of mercury at the ESP outlet. The vapor-phase mercury removals for Darco HgTM, Darco Hg-LHTM, and the Darco HgTM Carbon-Miller ash were within $\pm 10\%$ of each other over the range of injection rates, which may be within the variability of process conditions and the measurement uncertainty.

Figure 3-15 shows the percent mercury removal across the ESP for all of the Darco HgTM sorbents tested on Unit 1. This plot combines the performance of the Darco sorbent tested in March 2004 and January 2005, along with the Darco Hg-Miller ash blend and the brominated Darco Hg-LH. The Darco HgTM tested in January 2005 showed significantly better performance when compared to the Darco HgTM tested in March 2004. At an injection rate of approximately 5 lb/MMacf, the Darco HgTM tested in March 2004 provided a mercury removal of 58%, whereas the Darco HgTM tested in January 2005 provided a mercury removal of 69% at the same injection rate. The high mercury removal during January 2005 may be partly attributed to the relatively lower ESP inlet temperatures experienced during that injection testing period. During the January 2005 testing, the AHO temperature ranged from 275 to 290 °F, whereas, during the March 2004 testing, the AHO temperature ranged from 303 to 306 °F.

Figure 3-16 shows the percent mercury removal across the ESP for the two HOK sorbents tested on Unit 1. This plot combines the performance of the Super HOK carbon tested in March 2004 with that of the Coarse HOK carbon tested in January 2005. The Coarse HOK demonstrated a maximum mercury removal similar to that of the Super HOK.

Coal, Fly Ash, JBR FGD Byproducts, and Other Process Streams

Coal

Table 3-17 shows the analytical results for the as-fired coal samples gathered during the January 2005 parametric tests. Composite samples of the Unit 1 coal were collected once daily upstream of the coal pulverizers and were analyzed in triplicate for mercury; an average of the triplicate analyses is reported in the table. Ultimate/proximate and chlorine analyses were performed on selected samples, and these results are also shown.

Fly Ash

Table 3-18 shows the results for mercury and LOI analyses of the ESP fly ash samples. Composite fly ash samples were obtained during the baseline characterization and sorbent injection test periods. The carbon content of the ESP fly ashes, as measured by percent LOI, were very similar during the injection testing, but there was no ESP ash collected during the baseline to compare to the injection test results.

Table 3-17. Unit 1 – Coal Analyses for Baseline and ACI Parametric Tests

Date	1/17	1/18	1/19	1/20	1/21
Sample Time (EST)	17:00	10:33	n/a	14:30	10:00
Test Condition ^a	BL	HOK	Darco-Hg/Miller ash Blend	Darco Hg-LH	Darco Hg
Proximate, wt % as received					
Moisture	8.75	6.49		5.47	
Ash	13.08	12.04		12.50	
Volatile Matter				32.12	
Fixed Carbon				49.91	
Ultimate, wt % as received					
Carbon				68.85	
Hydrogen				4.47	
Nitrogen				1.54	
Sulfur	1.07	1.39		1.47	
Oxygen				5.70	
Heating Value (Btu/lb, as received)	11790	12293		12330	
Mercury (µg/g, dry)	0.077	0.137	0.090	0.130	0.099
Mercury (lb/trillion Btu)	6.5	11.2		10.6	
Chlorine (mg/kg, dry)	290			272	

Table 3-18. Unit 1 – ESP Fly Ash Analyses for Baseline Characterization and Sorbent Injection Tests

Date	Time (EST)	Sample Type	Test Condition	Injection Rate (lb/MMacf)	Mercury (mg/g)	LOI (%)
1/18	~12:30	ESP Ash	Coarse HOK	5.0	0.64	13.9
1/19	~12:30	ESP Ash	Darco Hg TM -Miller	5.0	0.54	12.2
1/20	~12:30	ESP Ash	Darco Hg TM -LH	5.0	0.62	12.0
1/21	~12:30	ESP Ash	Darco Hg TM	2.4	0.77	11.6

Method 26 Flue Gas Measurement Results from January 2005 Parametric Tests

Method 26 measurements were performed during the initial baseline test period as well as during the Darco Hg-LHTM carbon injection test period. Measured flue gas concentrations of HCl and Cl₂, HBr and Br₂, and HF at the ESP outlet are summarized in Table 3-19 and Table 3-20. During the Darco Hg-LHTM injection, there was a significant

increase in the level of HBr in the flue gas downstream of the injection point relative to baseline. Since Darco Hg-LH™ is a brominated carbon, this suggests that a portion of the bromine associated with the carbon desorbed during injection. Furthermore, these data imply that the amount of bromine desorbed into the flue gas is related to the injection rate of the brominated carbon. Injection of the brominated carbon resulted in a five-fold increase in the amount of HBr in the flue gas. For a 100 MW, 1 ppm of HBr in the flue gas is equivalent to 10 ton/yr of HBr emissions. Units equipped with scrubbers would most likely remove the flue gas HBr.

Table 3-19. Unit 1 – Method 26A Data at ESP Outlet for Baseline Characterization Tests

Injection Rate (lb/hr)	HCl (ppmv)	Cl₂ (ppmv)	HBr (ppmv)	Br₂ (ppmv)	HF (ppmv)
Baseline	25.71	<0.08	0.18	<0.36	12.73

*all concentrations corrected to 3% O₂

Table 3-20. Unit 1 – Method 26A Data at ESP Outlet for Darco Hg-LH Characterization Tests

Injection Rate (lb/hr)	HCl (ppmv)	Cl₂ (ppmv)	HBr (ppmv)	Br₂ (ppmv)	HF (ppmv)
143	18.71	0.13	0.86	<0.39	13.31
200	17.95	0.40	1.20	<0.46	12.02

*all concentrations corrected to 3% O₂

3.2 Long-Term Carbon Injection Test Results

A month-long activated carbon injection test was conducted at Plant Yates Unit 1 with RWE Rheinbraun's Super HOK activated carbon. For the majority of the injection test, Unit 1 operated at a load set by grid demand. This load was typically 55 MW. During one week of the test, Unit 1 operated at full load (107 MW) during the 6 am – 6 pm time period, and operated at reduced load overnight.

Figure 3-17 shows the mercury concentration measured at each of the SCEM locations, along with the carbon injection rate. The mercury concentrations are represented in µg/dry Nm³ at 3% O₂. The carbon injection rate is in lb/Macf (details of calculation of lb/Macf values are in Appendix A). The data are plotted as hourly averages (the SCEM generates data every 3 to 4 minutes). Figure 3-17 spans the entire

month of the injection test as well as baseline data taken both prior and subsequent to the injection test.

Figure 3-18 shows the percent vapor phase mercury removals that were calculated from these data. Two removal values are charted: the vapor phase mercury removal across the ESP, and the vapor phase removal across the ESP/JBR scrubber system.

Baseline mercury removal across the Unit 1 gas path was characterized before the start of the long-term injection test and again at the end of the test. Because the HOK carbon was injected downstream of the ESP inlet measurement location, the ESP inlet values were not affected by the carbon injection. The ESP inlet mercury concentration ranged from 5 - 13 $\mu\text{g}/\text{Nm}^3$ during baseline and injection testing, with 60-75% oxidation.

At the ESP outlet, the baseline vapor phase mercury concentration ranged from 3 - 7 $\mu\text{g}/\text{Nm}^3$, with 55-80% oxidation. At the stack, the baseline vapor phase mercury concentration ranged from 1.5 to 3 $\mu\text{g}/\text{Nm}^3$. Baseline removal across the ESP was nominally 50%, and baseline removal across the system (ESP+JBR scrubber) was 70-80%. The baseline mercury removal measured across the ESP is in agreement with results measured during the baseline testing in Spring 2004. The baseline removal across the system was higher during the Fall 2004 testing than during the Spring 2004 tests. The mercury oxidation levels at the both the ESP inlet and outlet were also higher, indicating a possible explanation for the higher overall removal.

The carbon feed rate was adjusted throughout the injection test, in order to investigate the effect on outlet mercury concentrations. The effective carbon feed rates varied somewhat throughout the test period because of these manual adjustments and because of load, flow, and temperature variations during the testing. Because the flue gas flow rate changes with load, the carbon injection rate (lb/hr) was adjusted with load to maintain a constant volumetric-based injection rate (lb/Macf).

During the month-long test period, there were a few periods each consisting of several hours where the carbon injection rate dropped to zero. The carbon feeding occasionally stopped because of mechanical or electrical problems that occurred with the feed skid during the night and were not fixed until staff arrived on-site the following morning. For other short periods, the carbon injection rate was raised to as high as 16 lb/Macf in order to evaluate the effect on the ESP outlet particulate emissions. Excluding these brief periods of zero- and high-injection rates, the carbon injection rate was typically between 4 and 10 lb/Macf during the long-term test period.

Table 3-21 shows the range of vapor phase mercury removals measured across the ESP and across the system. As seen in Table 3-21 and Figure 3-18, there was significant variability in the mercury removal performance achieved during the test. Mercury

removal across the ESP ranged from 50 to 91%, with the majority of the data concentrated between 65 and 85%. The mercury removal across the ESP/JBR scrubber system ranged from 70 to 94%. From Table 3-22, it appears that increases in the carbon injection rate above 4.5 lb/Macf did not result in significant changes in the range of mercury removals measured.

Table 3-21. Range of Vapor Phase Mercury Removals Measured during Long-Term Injection Test

Injection Rate (lb/Macf)	Time Period	Range of Vapor Phase Hg Removals Measured across ESP (%)	Range of Vapor Phase Hg Removals Measured across System (%)
0	Pre and post long-term test	~50	70 - 80
4.5	11/23 17:00 – 12/5 5:00	50 – 91*	71 – 96
6.5	11/18 17:00 – 11/22 12:00	64 – 86	71 – 94
9.5	11/16 17:00 – 11/18 11:00; 12/11 0:00 – 12/13 4:00	67 – 86	75 – 92

* For the mercury removal across the ESP at an injection rate of 4.3 lb/Macf, 91 % removal was measured during one single hour; otherwise, the highest measured vapor phase mercury removal was 86%.

In Figure 3-19, the vapor phase mercury concentrations at the ESP outlet and the stack are plotted in lb Hg/trillion Btu. As seen in this plot, with no carbon injection, the ESP outlet concentration was between 2 and 3 lb/trillion Btu, while the stack mercury concentration was between 0.7 and 1.3 lb/trillion Btu. With carbon injection, the ESP outlet mercury concentration ranged from 0.4 to 3.2 lb/trillion Btu.

Effect of Load on Mercury Removal

The effect of high versus low load on mercury removal performance was evaluated. Low load was defined as an hourly average load less than 60 MW, while high load was defined as an hourly average load greater than 95 MW. The hourly mercury removal data from the month-long injection test were sorted by injection rate and average load.

Figure 3-20 shows the removal of vapor phase mercury across the ESP by the Super HOK activated carbon. It compares the low load and high load data from the long-term tests to the Spring 2004 parametric tests. The Spring 2004 tests were conducted at full load. The error bars on Figure 3-20 represent \pm one standard deviation. The error bars for the lower injection rates are larger than the error bars at the higher injection rates;

however, significantly more data were collected at the lower injection rates. Higher removal across the ESP was achieved during the long-term tests as compared to the parametric tests.

From the long-term test data in Figure 3-20, it appears that operation at high versus low load does not affect the mercury removal across the ESP. In Figure 3-21, the mercury removal across the ESP/JBR system is compared to the carbon injection rate at high and low loads. In this case, the system mercury removal is consistently lower at the high load condition.

Figure 3-22 is provided in order to compare the ESP removal to the system removal for the two load conditions. The long-term data from Figures 3-20 and 3-21 are combined to make this plot. At the low load condition, there is a significant increase in the overall system removal as compared to the ESP removal. However, for the high load condition, the overall system removal is either equal to or only slightly greater than the ESP removal, indicating little overall mercury removal by the scrubber at high load. Figure 3-23 shows that at high load the mercury removal across the JBR is less than 20%. There are three data points at high load and injection rates $> 10 \text{ lb/Macf}$ that appear to indicate negative removal of total mercury across the JBR scrubber. These three points were gathered on the same day. It is possible that there is some system performance or measurement bias for that day, so these data should not be given significant consideration in comparison to the rest of the data. The JBR performance data at high load appear to correlate very well with the Spring 2004 parametric test data, excluding the three data points at the highest injection rates.

The total mercury removal by the scrubber is affected by two main components: (1) the removal of soluble oxidized mercury by the scrubber and (2) the possibility of re-emissions of elemental mercury. Therefore, the effect of load on system mercury removal may be related to the following parameters: variations with load in scrubber efficiency for removal of oxidized mercury, changes in the oxidation state of mercury in the inlet scrubber gas, and scrubber re-emissions. These three parameters were evaluated, as discussed below.

When the SO_2 removal efficiency was plotted against the load for the time period of the long-term test, a marked decrease was observed in removal efficiency as load increased. A similar trend might be expected for other gas phase species such as oxidized mercury, thus inhibiting total mercury removal at high loads. However, it should be noted that the SO_2 removal efficiency was still at least 90% at the highest load condition. In contrast, the oxidized mercury removal ranged from 40 to 98% at low load, and 40 to 90% at high load.

The decrease in system removal at high load might be explained by a lower fraction of oxidized mercury at the JBR inlet during high load conditions. The oxidation state of the vapor phase mercury was plotted versus the injection rate and load condition, as shown in Figure 3-24. At the ESP outlet, the fraction of vapor phase mercury present as oxidized mercury is only slightly lower at high versus low load. The small decrease in oxidation state of the ESP outlet gas mercury from low to high load is not large enough to account for the marked decrease in total mercury removal across the scrubber at high load. However, there does not appear to be sufficient data to draw a general conclusion on the effect of load on ESP outlet oxidation.

It should be noted that the overall set of JBR-related mercury data does not point to either re-emissions or removal of elemental mercury by the scrubber. Figure 3-25 shows the hourly averages of the difference between the inlet and outlet elemental mercury concentrations across the scrubber. Positive values indicate elemental mercury removal while negative values indicate re-emissions. With no re-emissions, the two values should be equal. The average of the differences plotted in Figure 3-25 is $0.1 \pm 0.3 \mu\text{g}/\text{Nm}^3$, which is within the detection limit of the sampling system.

More data are needed to draw a definitive conclusion about how an increase in load results in lower total mercury removal.

Effect of Temperature on Mercury Removals Measured in Long-Term Test

In laboratory, fixed-bed tests, the adsorption capacity of activated carbon decreases with increasing temperature. In the full-scale application of ACI, the activated carbon does not reach equilibrium with the flue gas mercury; however, it is reasonable to expect the duct temperature to affect the reactivity of the carbon with the flue gas mercury.

The operating temperature of the ESP is a function of the unit load, as shown in Figure 3-26. Temperatures at high load are approximately 30°F higher than at low load. The A-side of the ESP inlet operates at approximately 30°F higher temperature than the B-side. The two sides combine in the ESP and have a common outlet, which is 40-50°F lower than the A side. Carbon injection occurs across both sides of the inlet to the ESP; however, mercury measurements are only made on the A-side of the inlet duct and the common outlet duct.

Figure 3-27 shows the mercury removal across the ESP as a function of temperature, with the load and carbon injection rate identified for each point. Carbon injection rates (in lb/Mmacf) are indicated by the different legend symbols. For the purposes of this analysis, high load was considered to be greater than 95 MW, while low

load was between 50 and 60 MW. All data above 285°F are from the high load operating condition and are indicated by the dashed circle. This plot does not show a strong correlation between mercury removal and the ESP operating temperature.

Collection and Analysis of Solids Samples

Coal, ash, and FGD byproduct samples were collected during the long-term injection test and analyzed. Table 3-22 shows the coal ultimate/proximate results, and Table 2-23 shows the mercury and chloride values measured for selected samples.

Table 3-22 Coal Ultimate/Proximate Results from Long-term Test.

Date	11/13/04	11/14/04	11/17/04	11/19/04	11/22/04	11/29/04	12/5/04	12/6/04	12/9/04	12/10/04
Sample Time	13:15	12:50	11:15	8:40	10:10	8:00		12:55	14:15	12:55
Test Condition ^a										
Proximate, wt % as received ^b										
Moisture		5.27		4.44		5.93	5.16			6.28
Ash		11.05		10.73		11.11	10.93			11.65
Volatile Matter		38.83		32.10		32.36	31.55			31.64
Fixed Carbon		44.85		52.73		50.60	52.36			50.43
Sulfur		1.36		1.22		1.17	1.24			1.30
Ultimate, wt % as received										
Moisture		5.27		4.44		5.93	5.16			6.28
Carbon		70.13		70.4		68.56	69.80			68.30
Hydrogen		4.61		4.82		4.79	4.75			4.70
Nitrogen		1.53		1.52		1.45	1.47			1.44
Sulfur		1.36		1.22		1.17	1.24			1.30
Oxygen		6.05		6.87		6.99	6.65			6.33
Ash		11.05		10.73		11.11	10.93			11.65
Heating Value (Btu/lb, as received)		12609		12851		12535	12774			12385
Mercury (µg/g, dry)	0.055	0.100	0.078	0.068	0.037	0.090	0.101	0.068	0.046	0.154
Mercury (lb/trillion Btu)		7.5		5.1		6.8	7.5			11.7
Chloride (mg/Kg, dry)			112			119 (coal sampled 11/30)				122

Table 3-23. Coal Hg and Cl Values for Selected Samples from Long-Term Test

Coal Sample Date	Coal Hg (ug/g)	Coal Cl (mg Cl/kg)
11/3/2004	0.055	
11/14/2004	0.100	
11/17/2004	0.078	112
11/19/2004	0.068	
11/22/2004	0.037	
11/29/2004	0.090	
11/30/2004		119
12/5/2004	0.101	
12/6/2004	0.068	
12/9/2004	0.046	
12/10/2004		122

Table 3-24 shows the ash mercury and LOI contents for selected samples. A diagram of ESP is shown in Figure 3-28. The ESP is equipped for sampling from hoppers 2, 3, 6, and 7. A composite sample was taken of hoppers 2 and 3, with 50% of the ash coming from each hopper. Likewise, a composite sample was taken of hoppers 6 and 7.

In general the mercury concentration of Hoppers 6/7 was higher than Hopper 2/3. There does not appear to be a consistent trend in the relative LOI concentration between the two sets of hoppers.

On 12/1/04, separate samples were taken from each of the four hoppers. All four samples were analyzed to note differences in composition between hoppers 2 and 3 and between hoppers 6 and 7. The difference in mercury content between hoppers 2 and 3 is within the range of mercury concentrations measured throughout the test. A similar conclusion is drawn from the hopper 6 and 7 samples on 12/1/04.

Table 3-24. Ash Hg and LOI for Selected Samples from Long-Term Test

	Hg (ug/g)		% LOI	
SAMPLE ID	Hopper 2/3	Hopper 6/7	Hopper 2/3	Hopper 6/7
11/15/2004	0.44	0.66	10.1	9.7
11/19/2004	0.57	0.57	13.5	12.1
11/29/2004	0.35	0.74	5.3	6.4
12/1/04, Hopper 2	0.26		6.1	
12/1/04, Hopper 3	0.36		9.9	
12/1/04, Hopper 6		0.53		8.8
12/1/04, Hopper 7		0.60		14.1
12/6/2004	0.43	0.70	11.2	14.2
12/10/2004	0.29		17.4	
12/13/2004	0.64	0.54	12.5	18.3

Table 3-25 shows the mercury concentrations of the FGD liquors sampled during the long-term test. The FGD liquor mercury concentration showed variability and ranged from 2.4 µg/L to 31 µg/L. The FGD liquor from baseline (no injection) testing had a concentration of 15 µg/L. Therefore, it does not appear that the mercury concentration of the liquor consistently, significantly increased during the long-term injection test. This result is not unexpected as the vapor phase mercury data indicated that less than 20% of the total mercury entering the scrubber was removed by the JBR scrubber.

Table 3-25. FGD Liquor Hg Concentrations for Selected Samples from Long-Term Test

FGD Slurry Sample Date	FGD Liquor Hg (ug/L)
11/14/2004	13.6
11/25/2004	10.4
11/26/2004	2.4
12/5/2004	23.5
12/10/2004	9.3
12/15/2004	31.2

Effect of Carbon Injection on ESP Operation

During parametric carbon injection testing in Spring 2004, erratic ESP arcing behavior was observed. The baseline (no injection) behavior of the ESP was also erratic, so it was not possible to correlate the ESP arcing with carbon injection rate. In the time that elapsed between the parametric tests and the long-term injection tests, the Unit 1 ESP underwent rigorous inspection and maintenance. The stand-off insulators at the bottom of the high voltage frame were found damaged or broken. It is unclear when this damage occurred (i.e. whether the damage is related to activated carbon injection during Spring 2004). It is believed that the presence of broken insulators would lead to erratic arcing and sparking behavior in the ESP, as was observed in the Spring 2004 testing. A visual inspection of the insulators revealed that carbon was “baked” onto the surface of the insulators.

In October 2004, some maintenance repairs were performed during a scheduled maintenance outage. During this outage the standoff insulators were either replaced or cleaned. This work was completed one month prior to the start of the continuous, long-term injection test. Thus, it was possible to study the ESP electrical behavior prior to carbon injection, during carbon injection, and post-injection.

The methodology and results of the ESP arcing analysis are described below. As will be seen from the analysis, arcing in the ESP was related in part to the injection of activated carbon. The ESP was inspected approximately two months after the conclusion of the long-term carbon injection tests. No visible signs of damage were observed. No damage to the standoff insulators, like the ones found in the October 2004 inspection, was found.

Methodology for ESP Arcing Analysis

Figure 3-28 shows the layout of the Unit 1 ESP. It is composed of four fields, labeled A, B, C, and D. When arcing at the Yates Unit 1 ESP occurs, it is highest in the first (A) field, then less in each subsequent field. For data presented here, the A, B, and C fields were analyzed. For some of the analysis, data for only the A field are presented because of the significantly higher arcing level observed in that field.

Raw data were obtained from the Unit 1 ESP in six-minute averages. These data spanned the time frame from 10/13/04 (the first day of ESP operation after the ESP overhaul) to 2/1/05 (approximately 1.5 months after the end of the long-term injection test). The data consisted of the unit load, ESP primary and secondary currents and voltages, arc rate, and spark rate for each field. These data were reduced to hourly averages, which were used for plotting purposes.

It was desired to evaluate the effect of load and carbon injection rate on the arcing rate in the first field of the ESP. Yates Unit 1 operated at two primary load ranges during the long-term injection test: low load (which ranged from 50 to 60 MW) and high load (which ranged from 95 to 107 MW). The ESP data were sorted by carbon injection rate and load in order to compute average arcing rates for various operational conditions. The average arcing rate was computed by averaging all the six-minute arc rates for which the load and injection rate met the specified criteria.

Pre-test injection behavior was analyzed with data covering the time period 10/13/04 to 11/15/04. Data prior to 10/13/04 were not analyzed because of the ESP overhaul that was conducted in early October. Post-injection test behavior was analyzed with data starting on 12/18/04, which is three days after injection was stopped, in order to allow for a return to baseline behavior. The ending date for the post-injection analysis was 1/17/05 because a second series of parametric carbon injection tests started on 1/18/05.

The ESP behavior before, during, and after the January 2005 parametric tests was also evaluated. For these analyses the time frame from January 8, 2005 to January 31, 2005 was analyzed.

Results of ESP Arcing Analysis

Figure 3-29 shows the arc rates for the first three fields of row 1 in the Unit 1 ESP. It also includes the load and carbon injection rate. This plot covers the time period 10/13/04 through 1/17/05. Several observations can be made from this plot and from a companion plot (Figure 3-30), which shows the average arc rates during various load and carbon injection rates.

- (1) The arc rate in the first (A) field is significantly higher than arcing in the B field, which is higher than arcing in the C field. Furthermore, arcing in the B and C field does not occur unless there is significant arcing in field A. While arcing in the first field was as high as 35 apm, no sparking was observed.
- (2) First field arcing during the carbon injection test period is higher than during non-injection periods. Prior to the long-term injection testing, the average arc rate at low load was 0.5 apm. During the long-term injection test, the average arc rate ranged from 4 to 5 apm at low load.
- (3) The arc rate is higher at high load versus low load. For a carbon injection rate of 4-5 lb/Macf, at low load the arc rate was 4 apm, while at high load the average arc rate was 17 apm. The increase in arcing at full load is seen for both injection and baseline cases.

- (4) At low load, the magnitude of the arcing does not appear to trend with the magnitude of the carbon injection rate. For example, the arc rate for injection rates between 3 and 4 lb/Macf was 4.6 apm, while the arc rate for injection rates greater than 7 lb/Macf was 5.2 apm. However, at high load, there may be an increase in arc rate with carbon injection rate (with data at either 3-4 or 4-5 lb/Macf excepted).
- (5) The ESP appears to have recovered from the carbon injection test to nearly pre-test arcing rates at low load. Pre-test arcing at low load was 0.5 apm, while post-test arcing at low load was 1.2 apm. However, given the volume of data available meeting the low load condition (561 hours of six-minute averages pre-test and 625 hours of six-minute averages post-test), this doubling of arc rate may be statistically significant.
- (6) Very little high load data were available during the pre and post-test periods (only 12 hours of six-minute averages per-test and 18 hours of six-minute average post-test). High load data will be analyzed from Summer 2005, to determine baseline arcing at high load. This analysis will be performed in the next quarter, when the data become available.
- (7) The opacity monitor at the ESP outlet is not a certified monitor, as it is used only for process information. The opacity monitor for Unit 1 measures 10% opacity when the unit is off-line. At low load, the opacity monitor also reads about 10%. No change in the opacity was noted when during carbon injection at low load. At high load baseline conditions, the opacity monitor reads 5 percentage points higher. For carbon injection rates less than 5 lb/Macf and high load, no further change in opacity was noted. For carbon injection rates greater than 5 lb/Macf and high load, a few percentage points increase in opacity was noted.
- (8) Method 17 traverses were conducted in the ESP outlet duct to quantify ESP outlet particulate emissions. A handful of the data collected exceeded the baseline (no injection) ESP outlet emissions measured in three Method 5 traverses from Spring 2004. Furthermore, a few data points exceeded the compliance limit for Yates Unit 1 (0.24 lb/MMBtu); however, the unit itself was in compliance because the downstream JBR removed the broken-through particulate matter (see next section for further discussion). There were visible signs of carbon on the Method 17 filters, confirming the breakthrough of carbon from the ESP. Figure 3-31 shows the ESP particulate emissions versus the carbon injection rate.

A second round of Unit 1 parametric carbon injection testing was conducted the week of January 18th, 2005. This testing began one month after the long-term carbon injection test had

ended. Figure 3-32 shows the Unit 1, row 1 ESP arc rates for the first two fields, load, and carbon injection rate. The plot spans the time period January 8 through January 31, 2005. The following observations can be made from Figure 3-32.

- (1) From the period January 8 through January 14, the arc rate in the first field was low. Starting January 14, the arc rate began to increase, and continued to do so through January 18, the start of the parametric carbon injection test. Some of this arcing behavior may be attributable to the load condition. No arcing was seen in the second field prior to the January carbon parametric tests.
- (2) On January 17, the unit was operated at full load and the first field arc rate was as high as 15 apm. On January 18, carbon injection began (once again full load) and the first field arc rate increased to as high as 35 apm. On January 19, the same high arcing behavior was seen.
- (3) On January 19, 2005 at 12:51 the arc rate in the first field abruptly dropped from 35 apm to 0 apm. The arc rates in the second and third fields remain elevated. It is unclear why the arc rate in the first field fell to zero; neither the carbon injection rate nor the load caused this change. This type of abrupt change in arcing behavior was not noted during the long-term injection tests, where arcing rates from 25 to 40 apm were seen over the course of a six-day period of high load operation. At the end of that high load operation during the long-term test, the arc rate gradually reduced to 10 apm, and at the end of carbon injection the arc rate gradually reduced to 1 apm.
- (4) The arc rate in the first field remained at zero for the remainder of carbon injection test and through the end of this data set (January 31, 2005). Meanwhile, arcing was still seen in the second and third fields throughout the carbon injection test.

Effect of Carbon Injection on Scrubber Operation

As mentioned in the previous section, activated carbon broke through the ESP during the long-term test period. This carbon was observed in samples of the JBR scrubber slurry. During the period of 25 November through 10 December the scrubber slurry was observed to be either black or dark in color. During this time period, the carbon injection rate typically ranged from 4 - 6 lb/Macf (with a few, brief periods at higher rates). Prior to and subsequent to this time period, the scrubber slurry did not show any visual evidence of carbon contamination. After December 10, the carbon injection rate was as high as 12 lb/Macf, yet no further darkening was observed. From this limited set of data, it does not appear that the breakthrough of carbon to the JBR scrubber is directly related to the magnitude of the carbon injection rate. The darkening of

the scrubber slurry is confirmed by measurements of the inert concentration of the JBR solids. The Yates JBR typically has an inerts concentration less than 2%. During the period in which the JBR solids were visibly darkened, the inert concentration ranged from 3 to 18% (see Figure 3-33).

3.3 Economic Analysis

An economic analysis was performed comparing the relative costs of the tested carbons for a permanent, full-scale mercury control system. The analysis was performed on a hypothetical 500-MW plant burning eastern bituminous coal, located in the Southeast. The results of the analysis are currently under review by the project team, and will be reported in the next quarter.

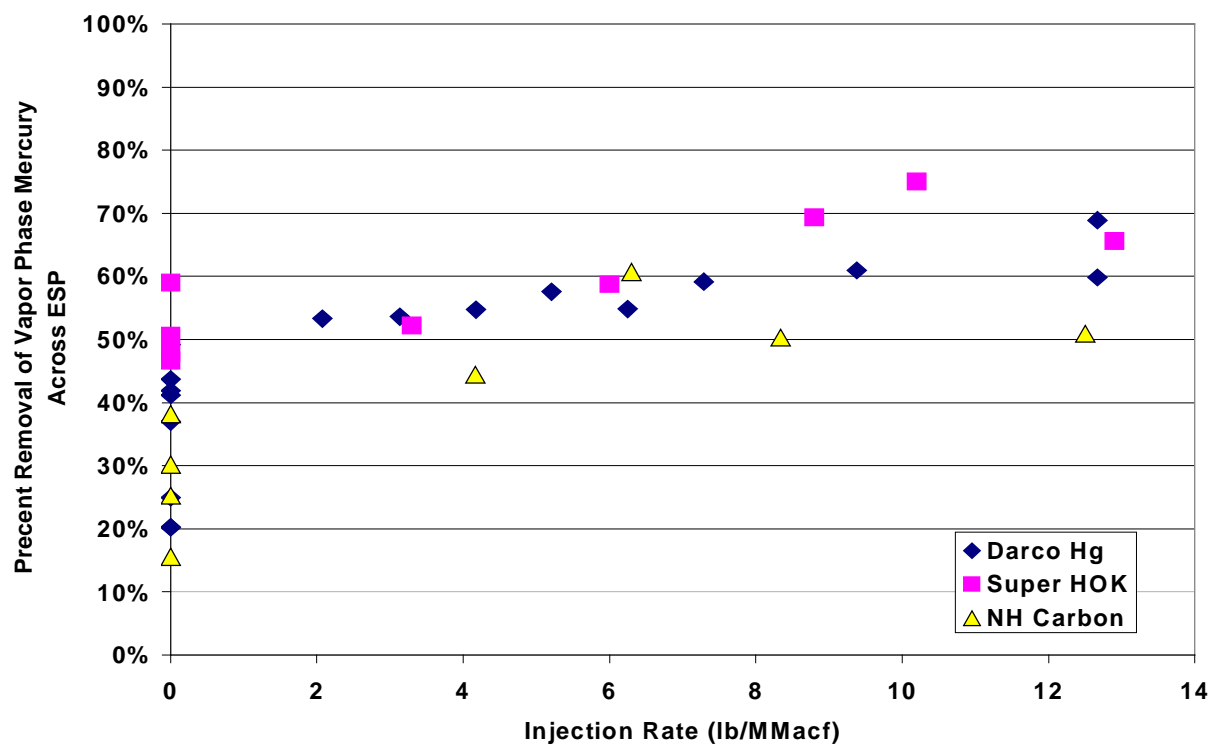


Figure 3-1. Comparison of Mercury Removal Efficiency Across the ESP for Darco Hg, Super HOK, and NH Carbon

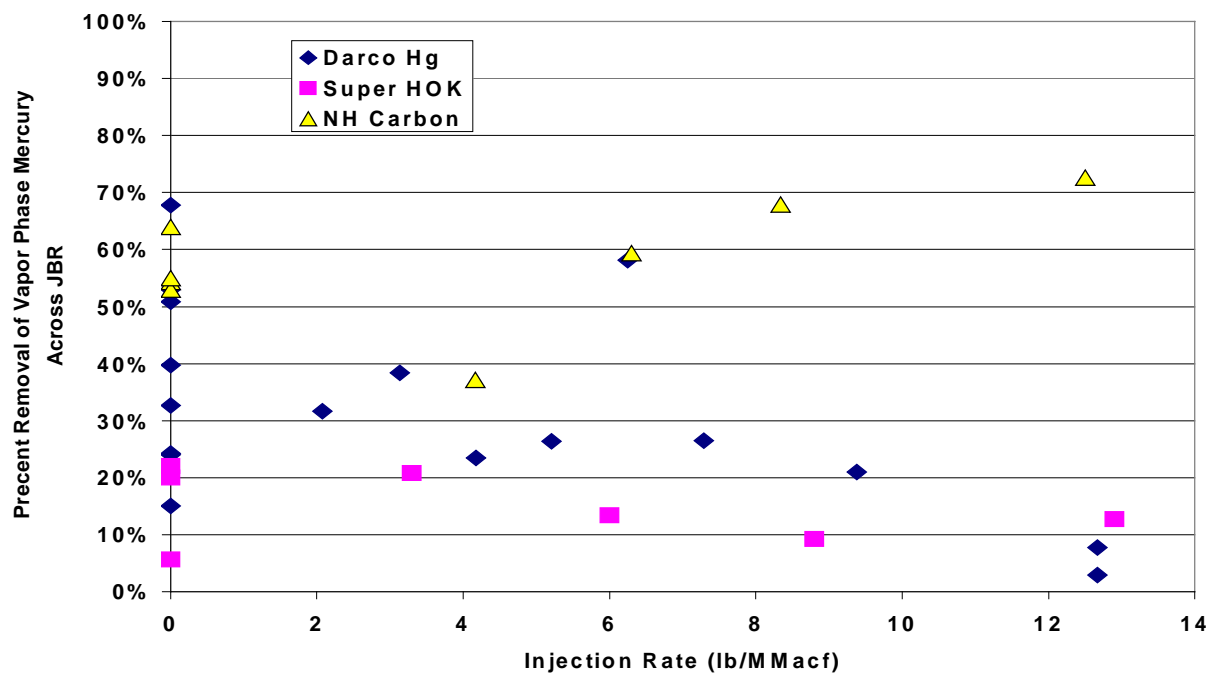


Figure 3-2 - Comparison of Mercury Removal Efficiency Across the JBR for Darco Hg, Super HOK, and NH Carbon

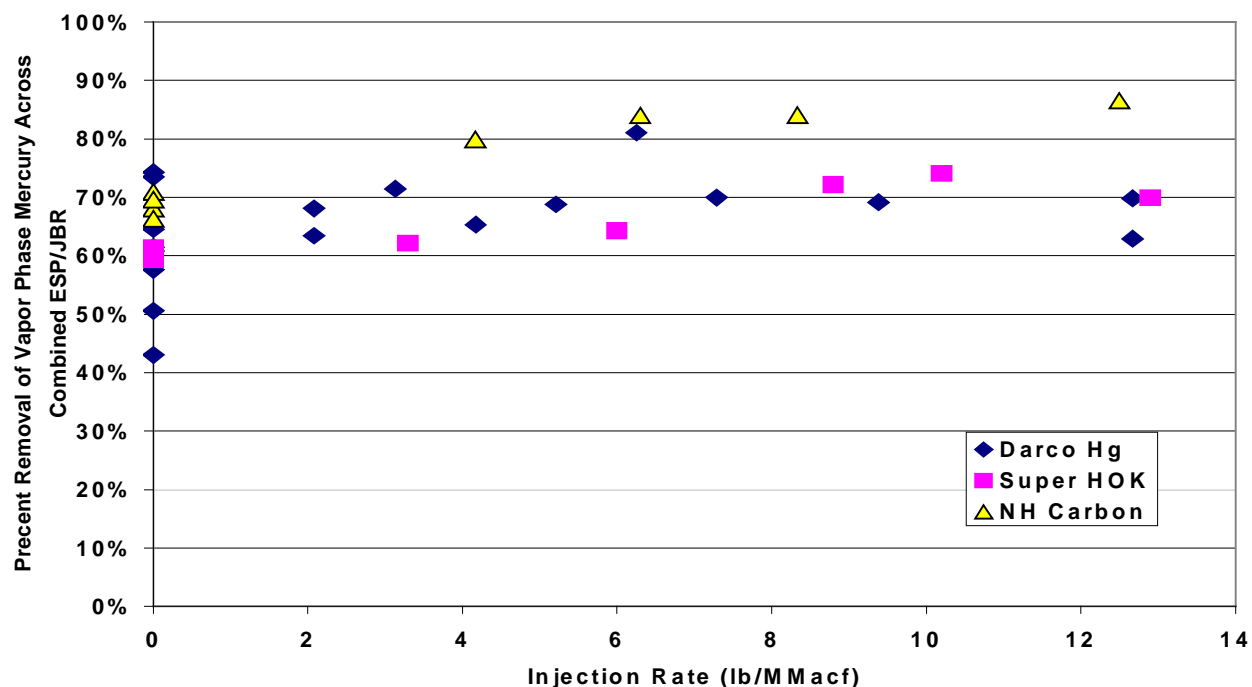


Figure 3-3. Comparison of Mercury Removal Efficiency Across the Combined ESP/JBR for Darco Hg, Super HOK, and NH Carbon

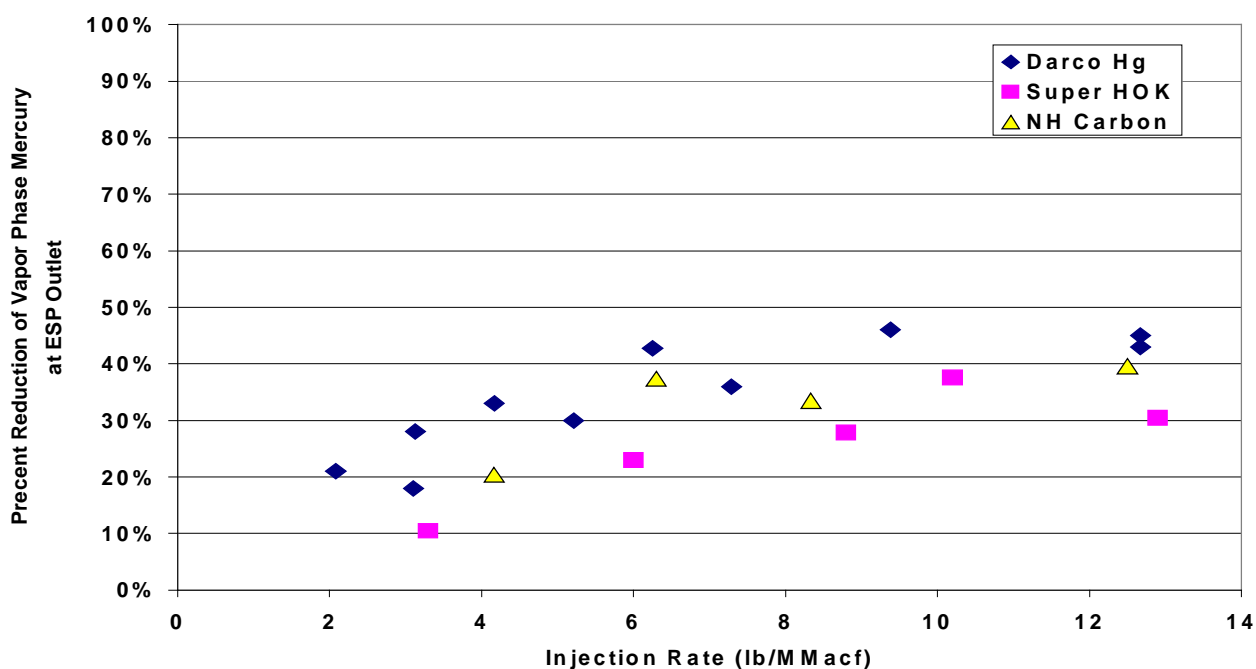


Figure 3-4. Comparison of Mercury Reduction at the ESP Outlet for the Three Sorbents Tested on Unit 1

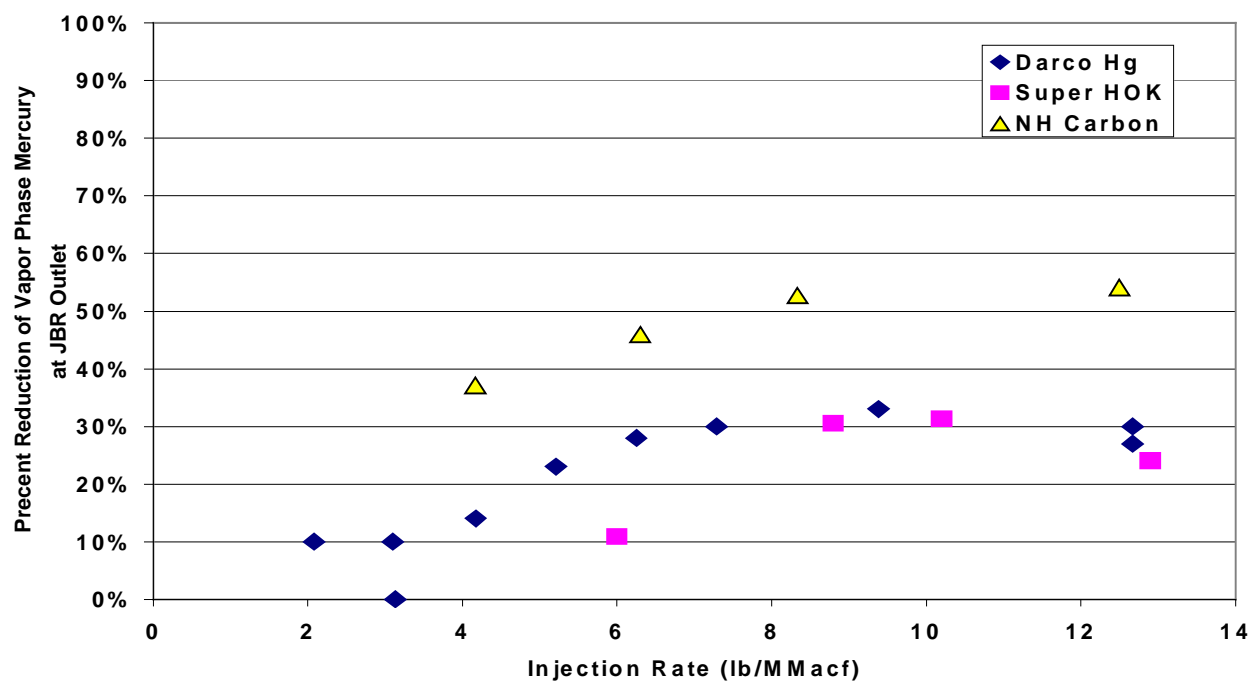


Figure 3-5. Comparison of Mercury Reduction at the JBR Outlet for the Three Sorbents Tested on Unit

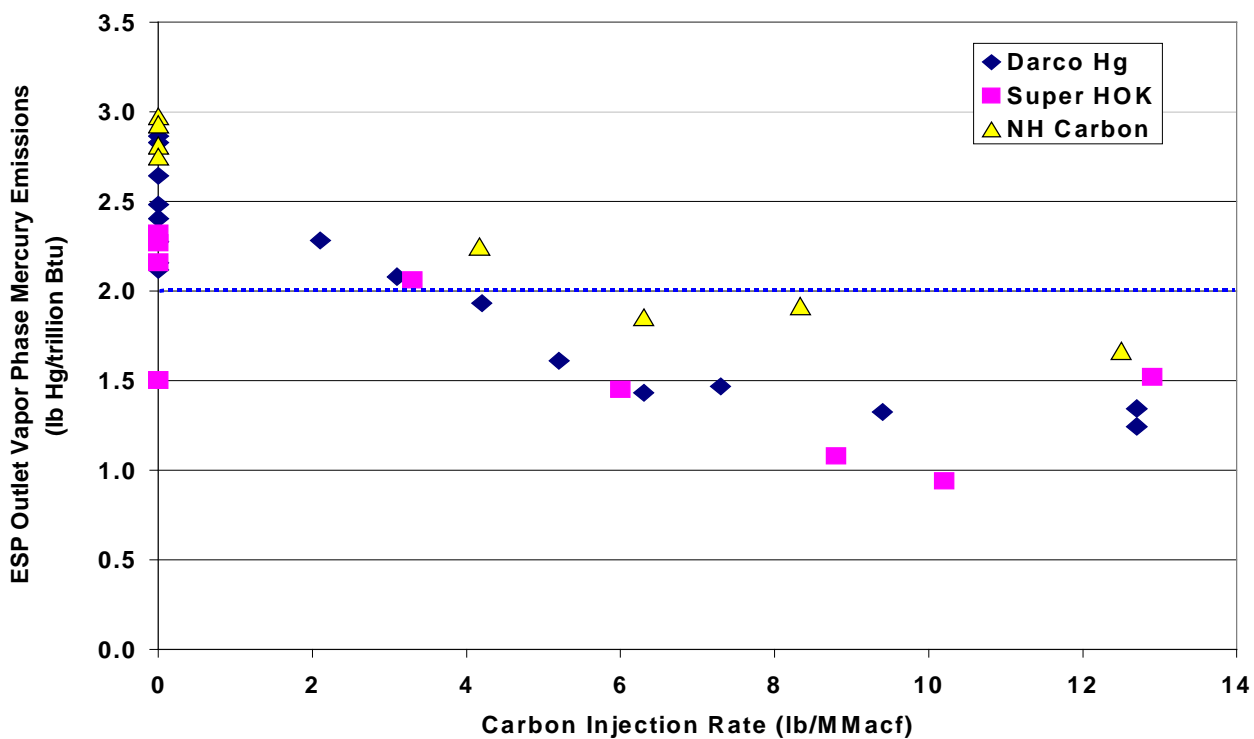


Figure 3-6. ESP Outlet Hg Emissions in lb Hg/trillion Btu for Darco Hg, Super HOK, and NH Carbon

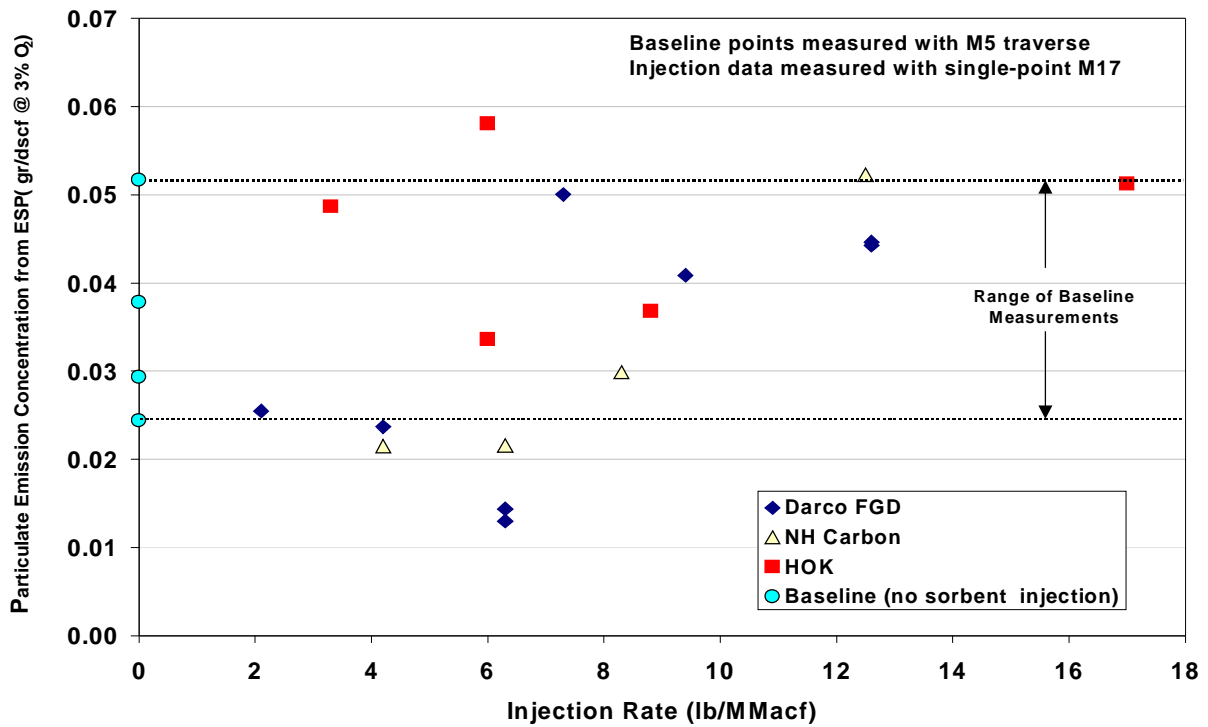


Figure 3-7. ESP outlet particulate emissions measured during Spring 2004 Unit 1 parametric carbon injection tests.



Figure 3-8. Damaged insulator from Yates Unit 1 ESP

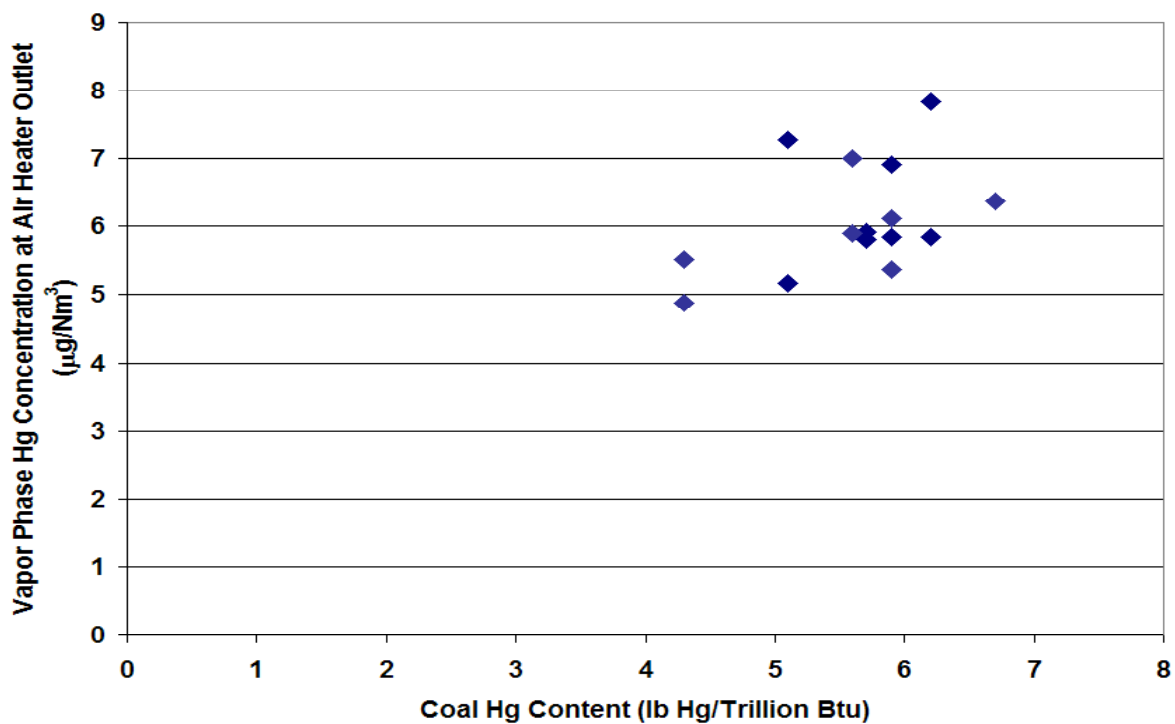


Figure 3-9. Air Heater Outlet Vapor Phase Mercury Concentration as a Function of Coal Mercury Content

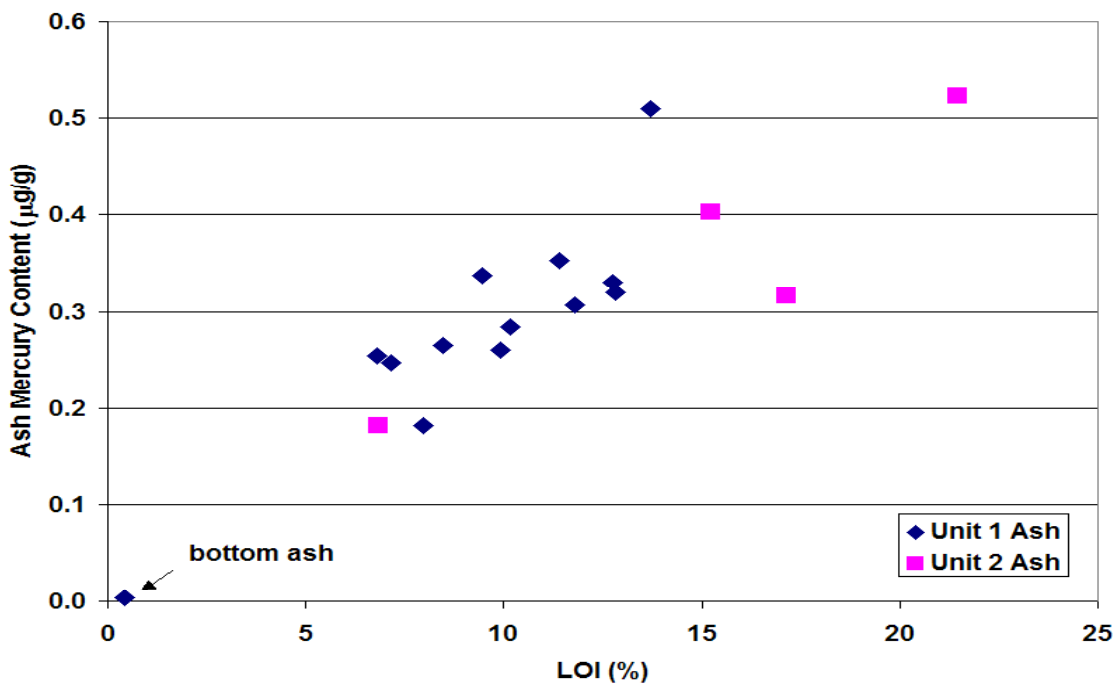


Figure 3-10. Ash Mercury Content as a Function of the Ash LOI Content

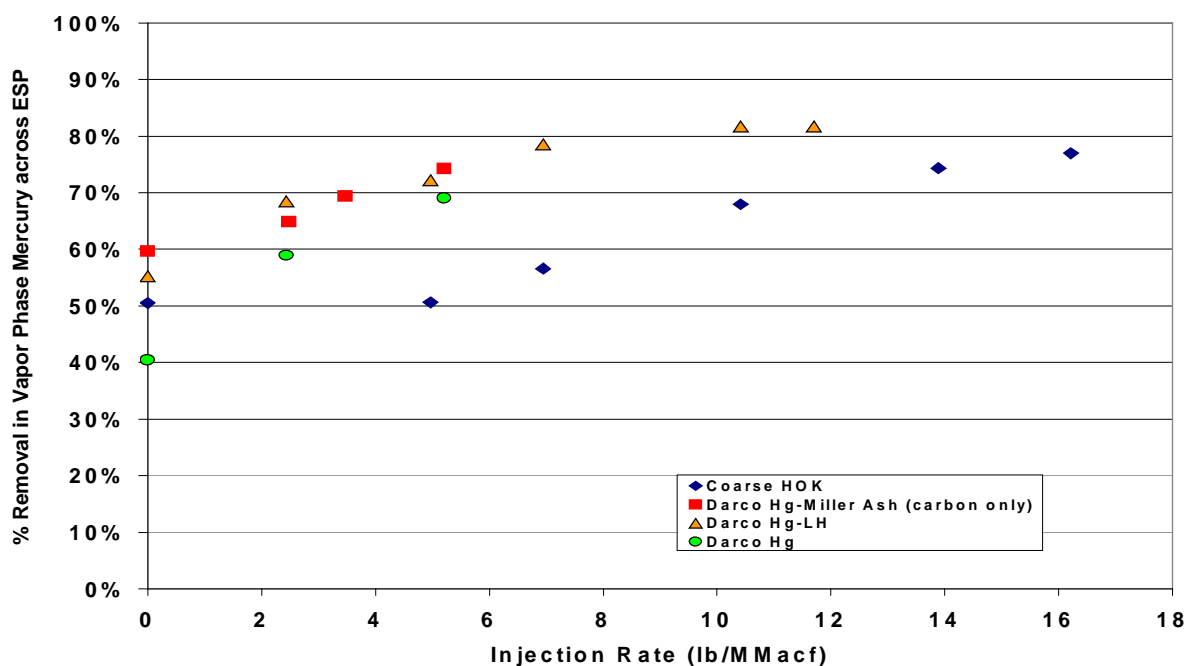


Figure 3-11. Percent Removal of Vapor-Phase Mercury across the ESP for the Sorbents Tested on Unit 1

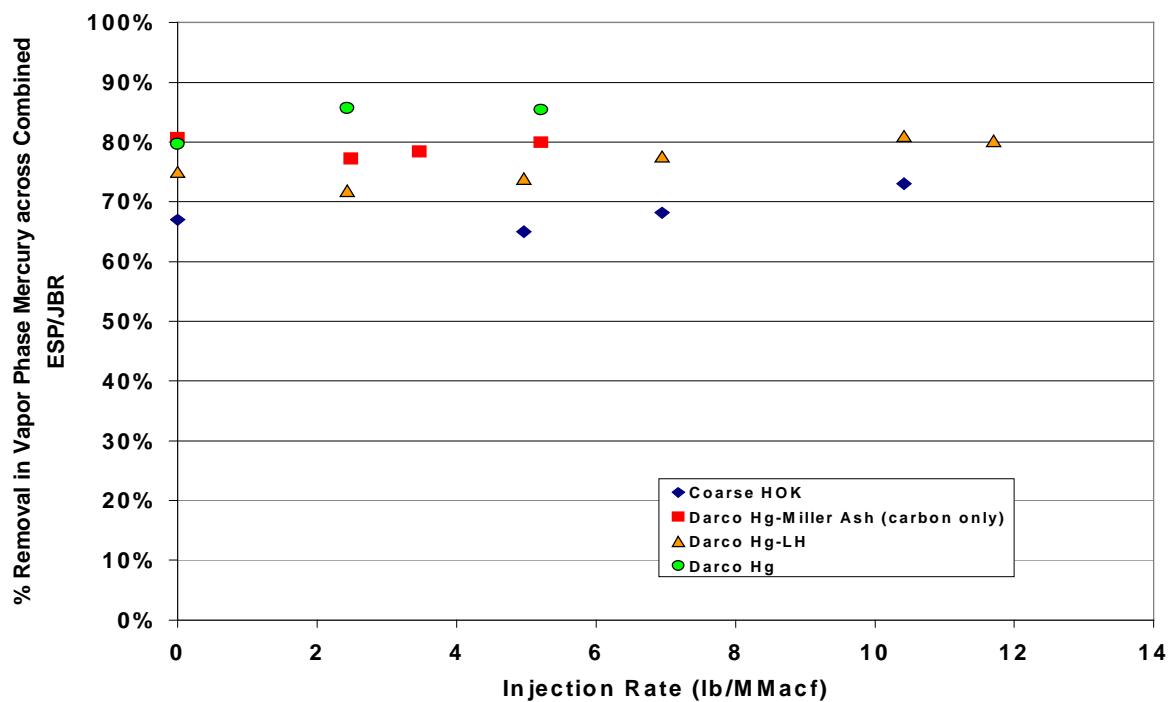


Figure 3-12. Percent Removal of Vapor-Phase Mercury across the Combined ESP/JBR for the Sorbents Tested on Unit 1 in January 2005

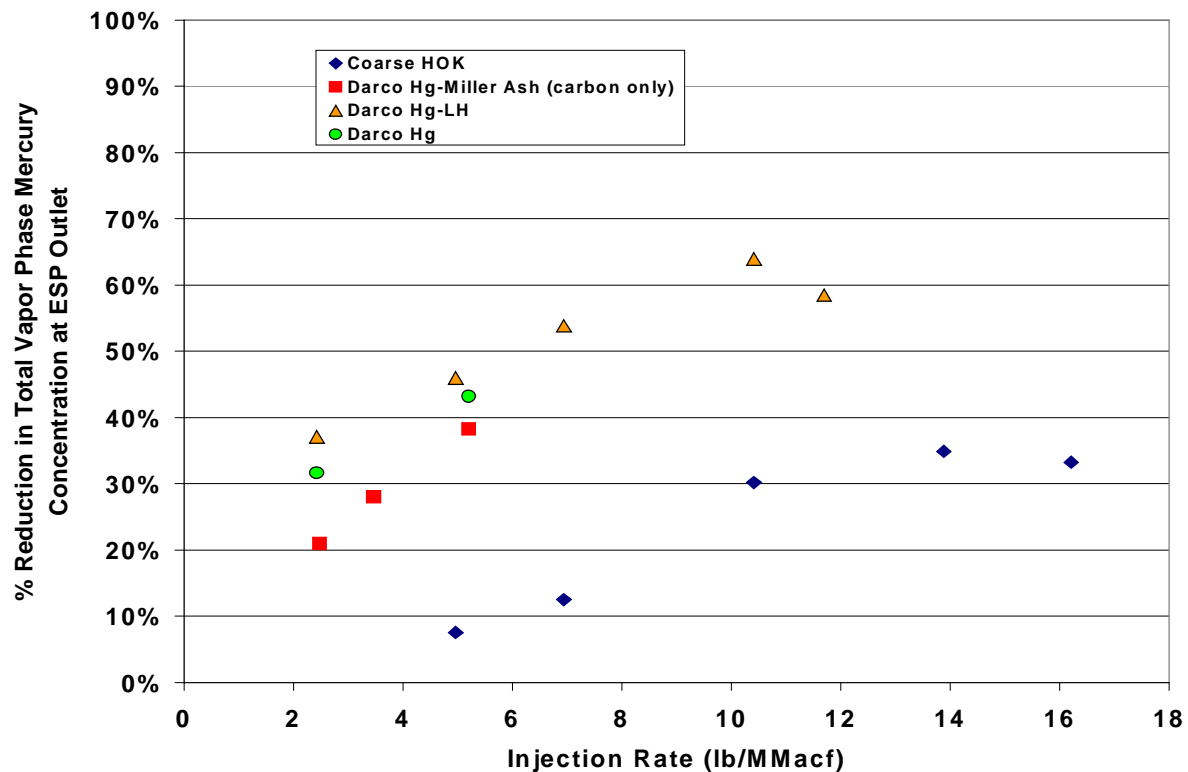


Figure 3-13. Percent Reduction of Total Vapor-Phase Mercury Concentration at the ESP Outlet Relative to Baseline for the Sorbents Tested on Unit 1 in January 2005

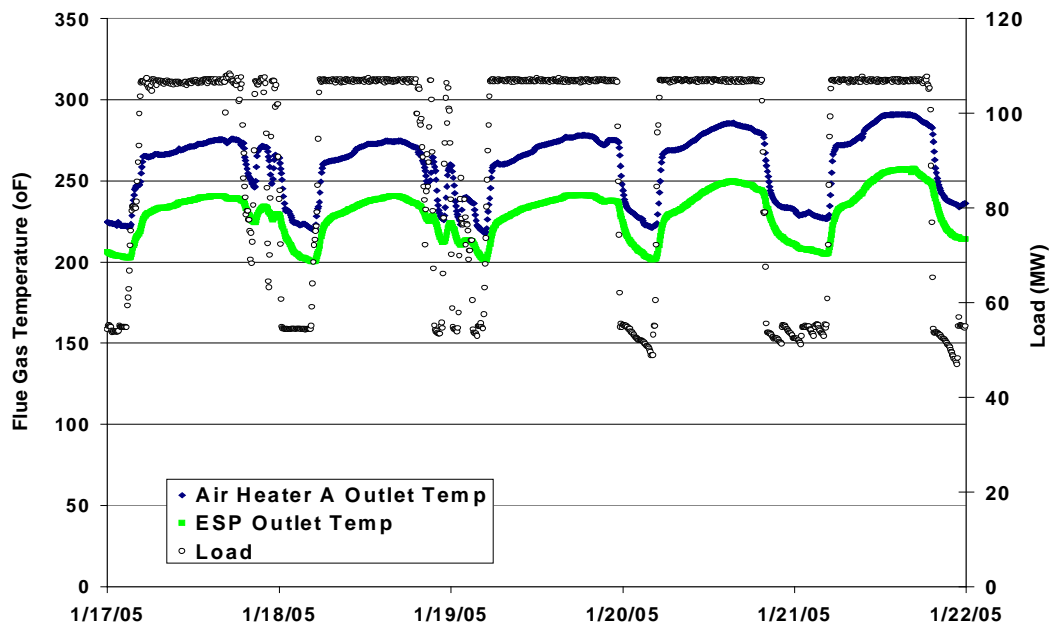


Figure 3-14. Unit 1 Air Heater Outlet and ESP Outlet Flue Gas Temperature During Baseline and Sorbent Injection Tests in January 2005

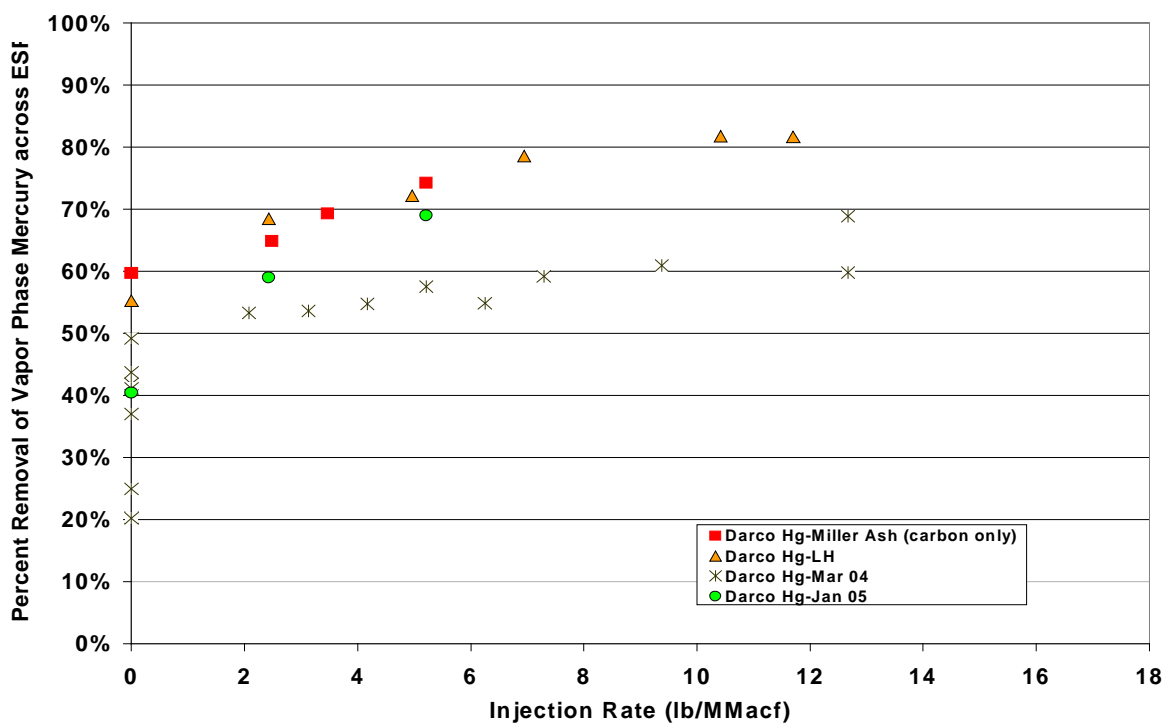


Figure 3-15. Percent Removal of Vapor Phase Mercury across the ESP for all of the Darco Hg Sorbents Tested on Unit 1

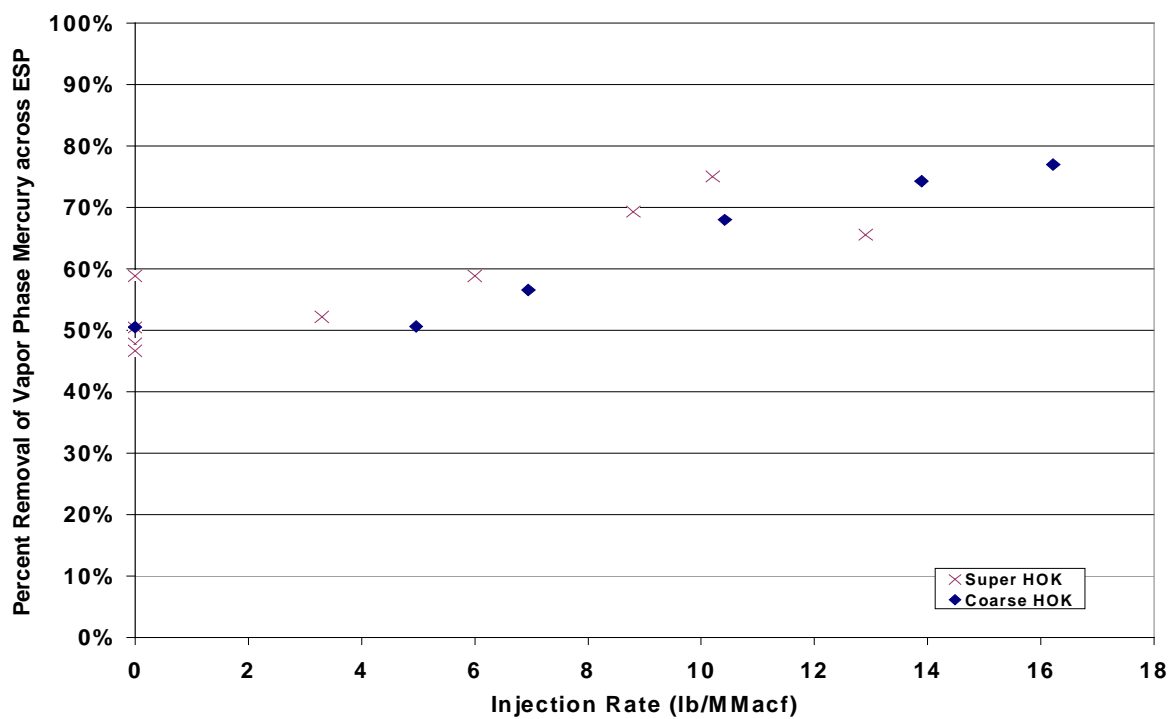


Figure 3-16. Percent Removal of Vapor Phase Mercury across the ESP for all of the HOK Sorbents Tested on Unit 1

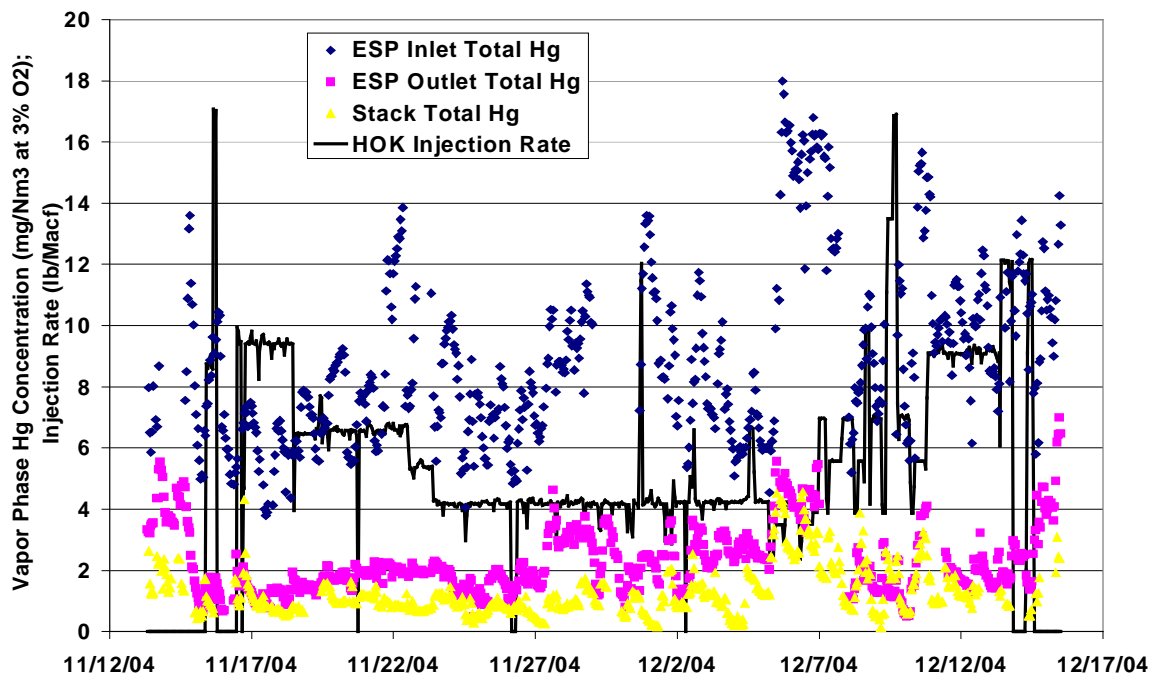


Figure 3-17. Vapor Phase Mercury Concentrations Measured at the ESP Inlet, ESP Outlet, and Stack During Long-term Injection Test

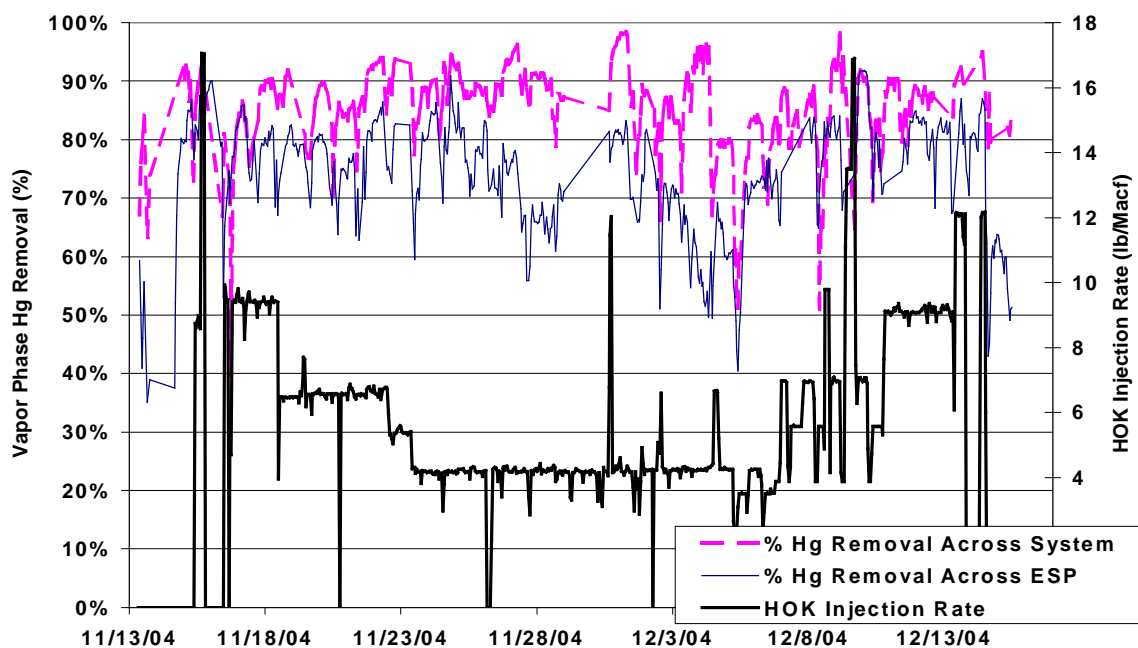


Figure 3-18. Vapor-Phase Mercury Removals Measured Across ESP and Across ESP/JBR System During Long-Term Test

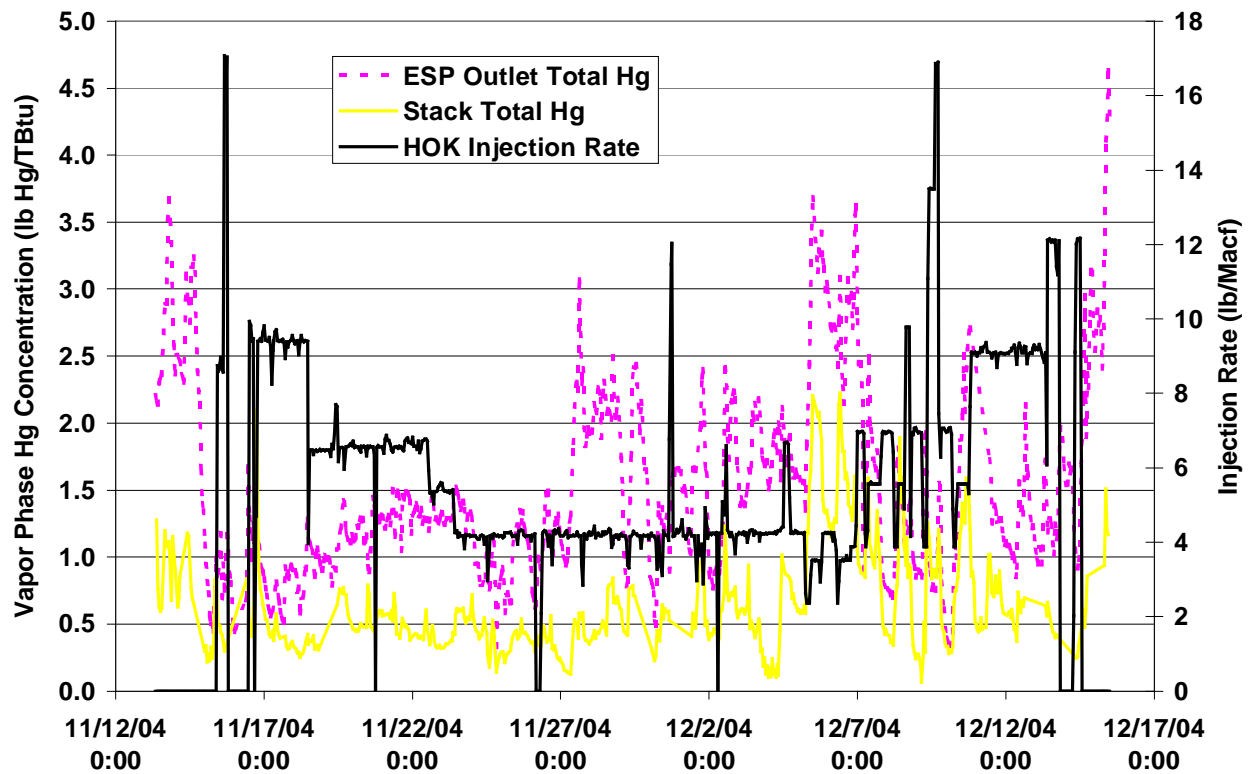


Figure 3-19. ESP Outlet and Stack Mercury Emissions in lb/trillion Btu.

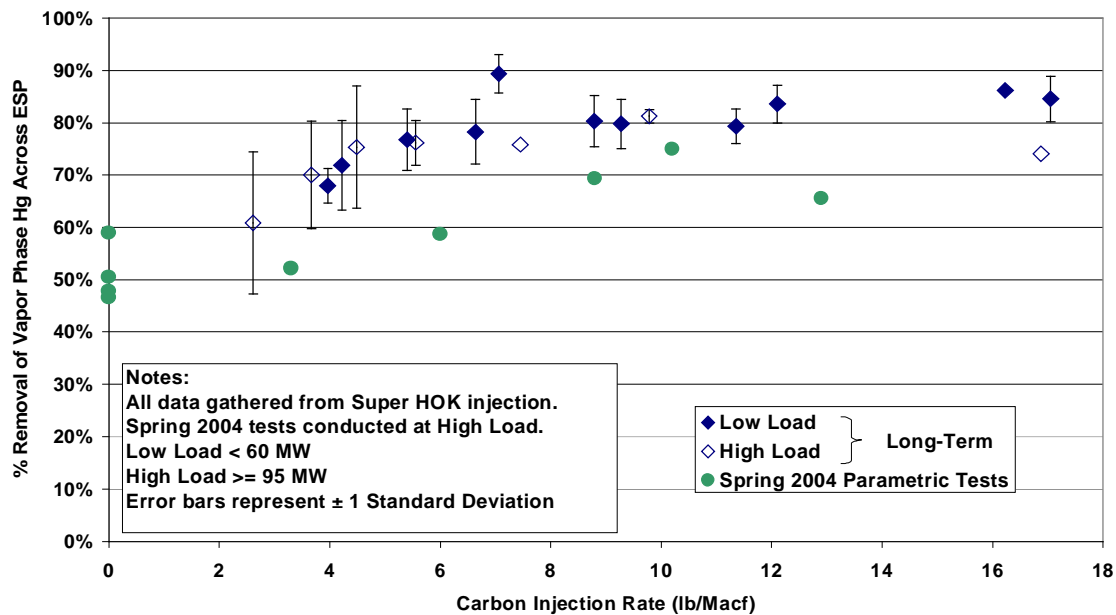


Figure 3-20. Comparison of Vapor-Phase Mercury Removal by Super HOK Across ESP for Parametric and Long-Term Injection Tests.

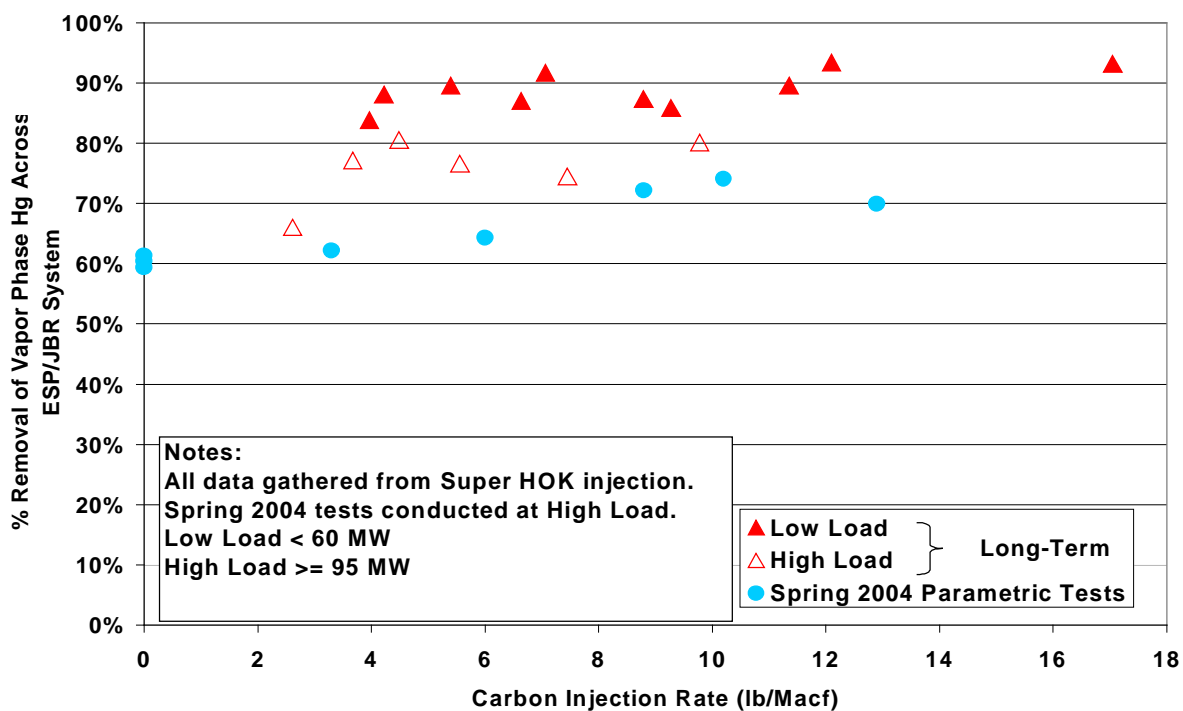


Figure 3-21. Comparison of Vapor-Phase Mercury Removal by Super HOK Across ESP/JBR System for Parametric and Long-Term Injection Tests.

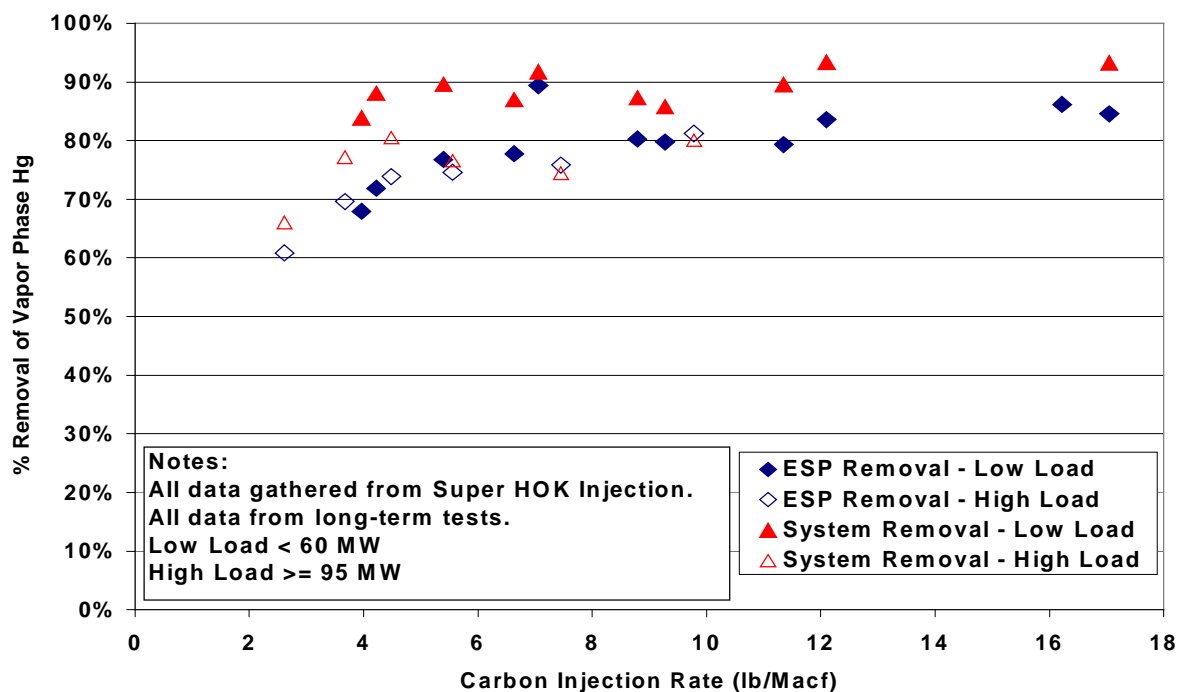


Figure 3-22. Comparison of Vapor-Phase Mercury Removal by Super HOK Across ESP and Across ESP/JBR System.

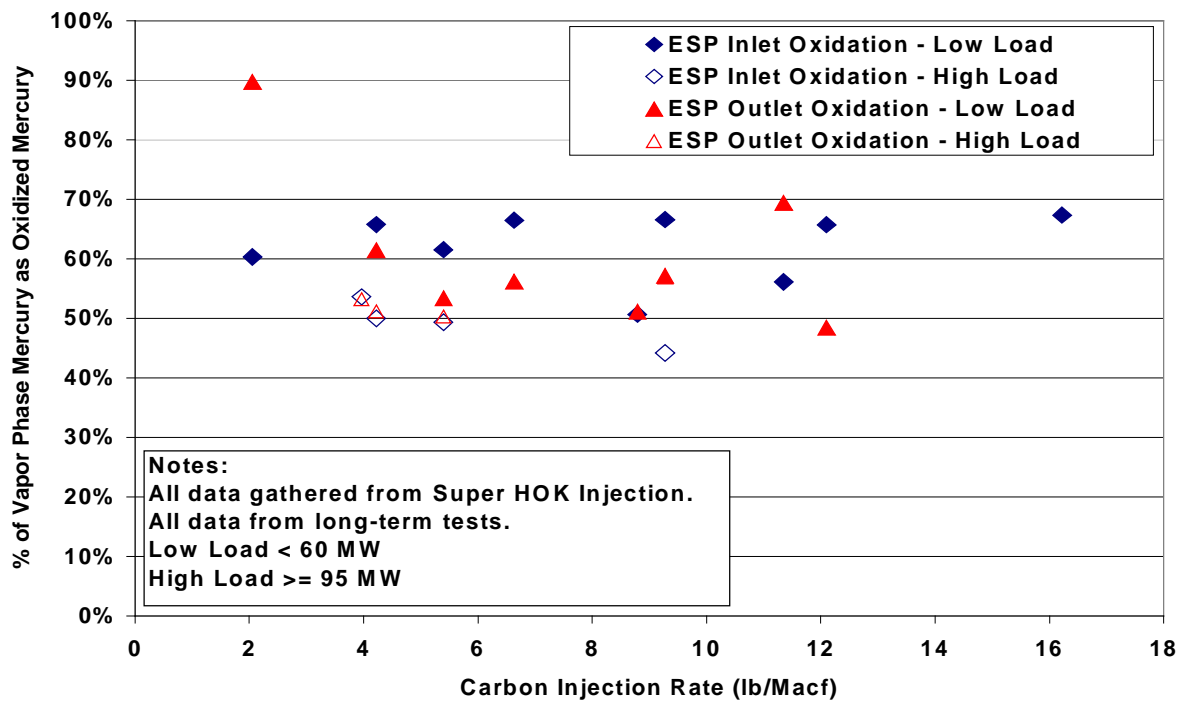


Figure 3-23. Vapor-Phase Mercury Removal across the JBR at High and Low Load Conditions.

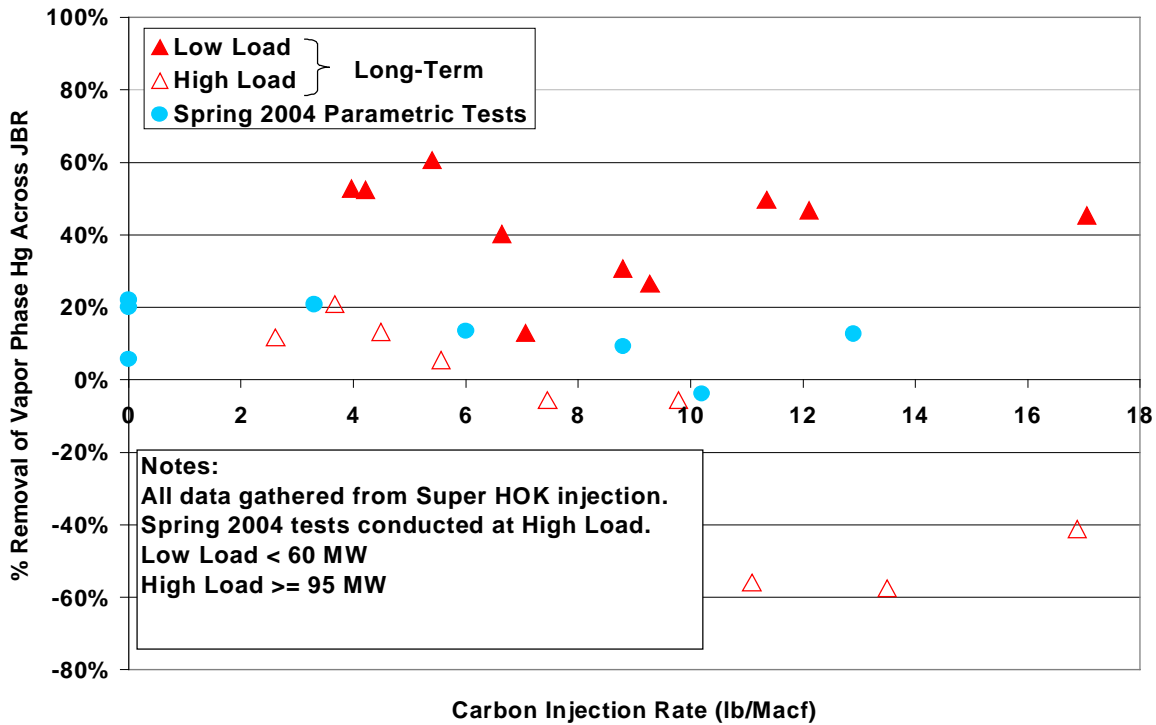


Figure 3-24. Vapor-Phase Mercury Present as Oxidized Mercury at ESP Inlet and Outlet.

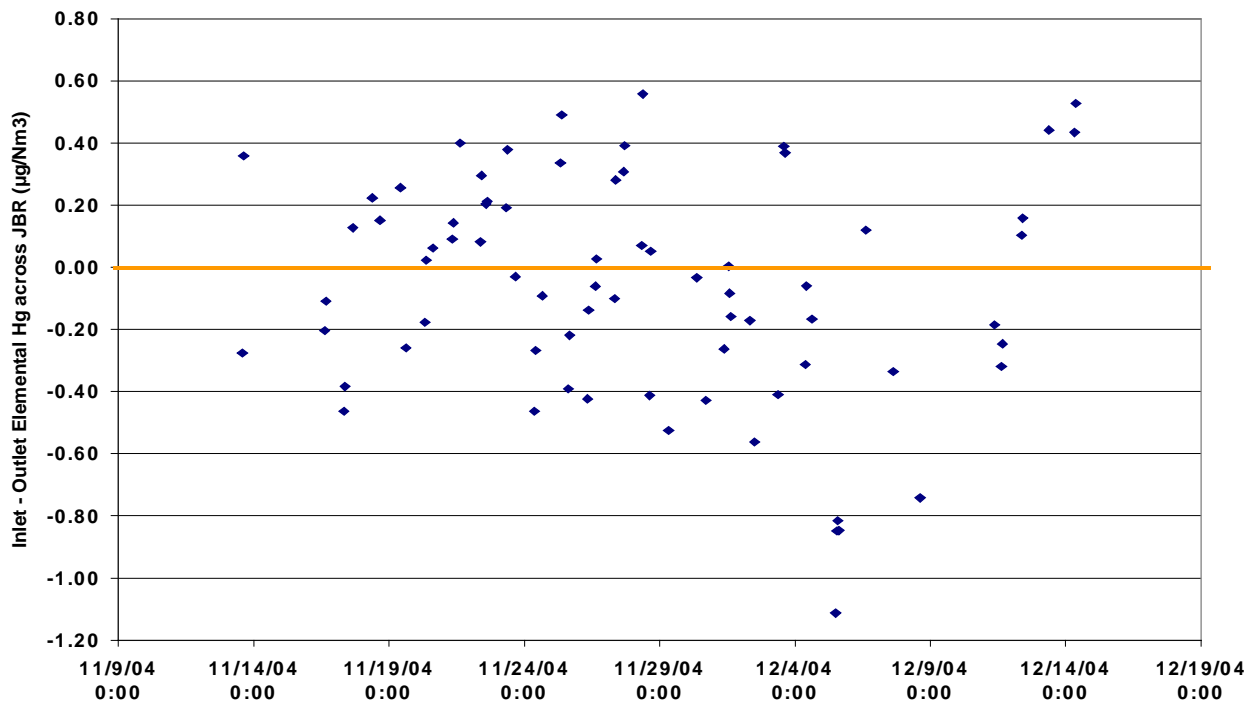


Figure 3-25. Difference between JBR Inlet and Outlet Elemental Mercury Concentrations.

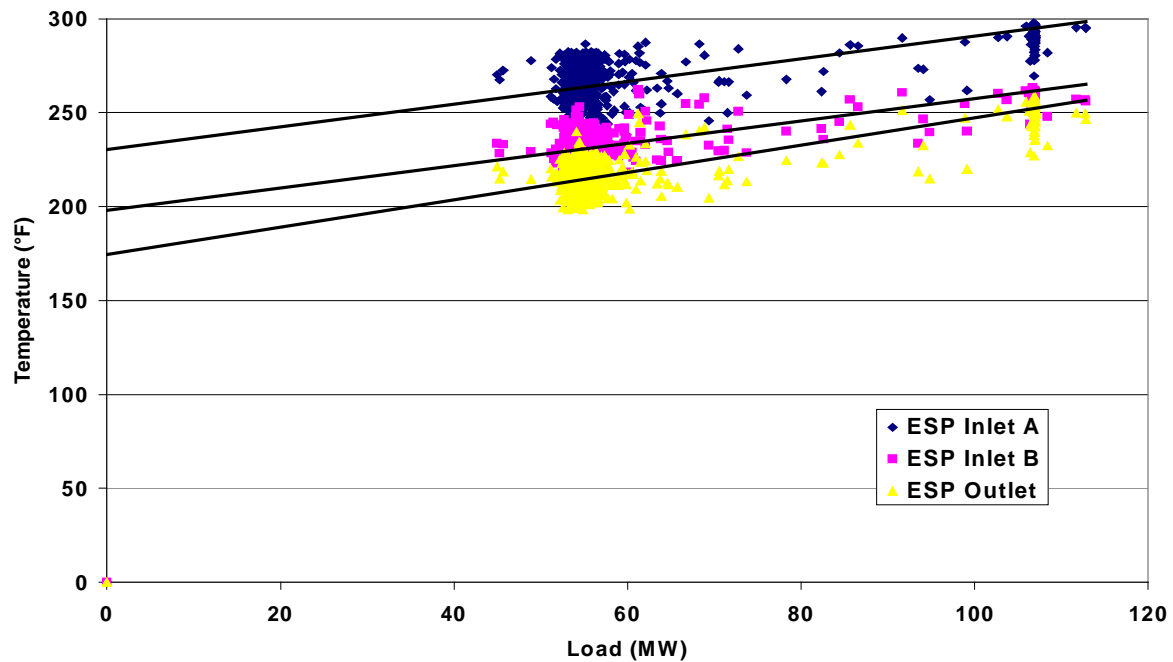


Figure 3-26. Effect of Unit Load on Unit 1 Duct Temperatures.

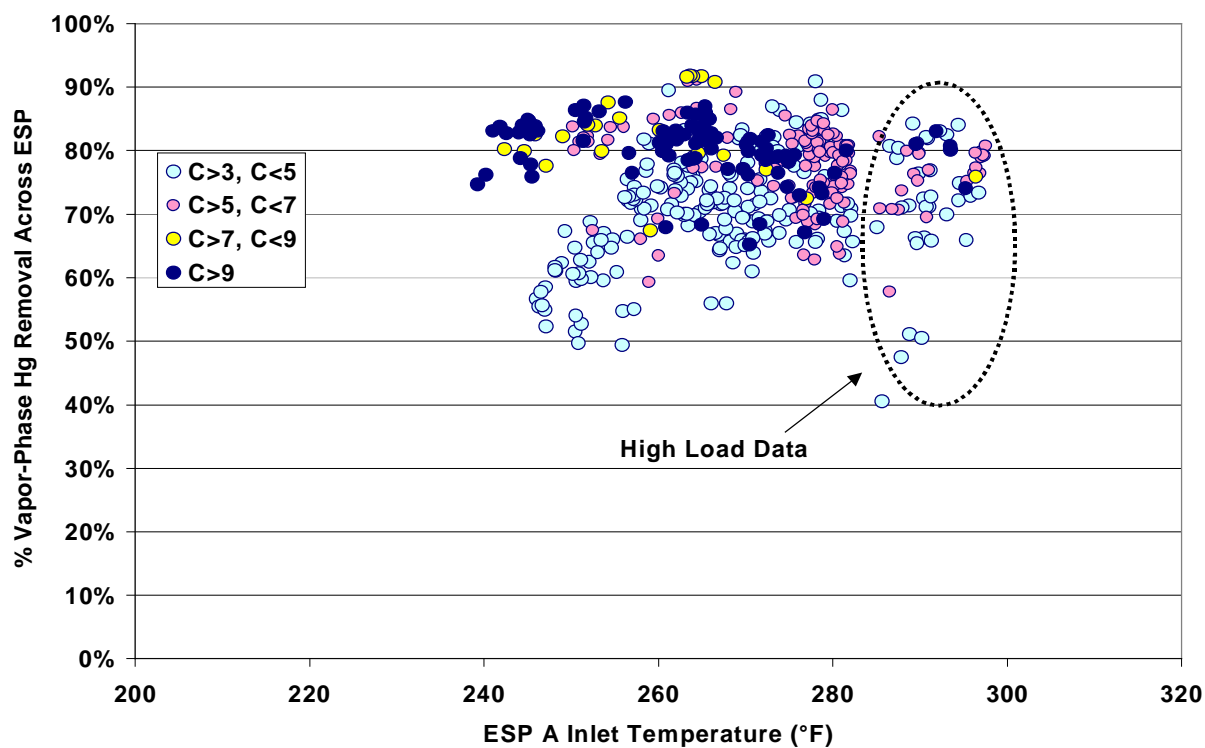


Figure 3-27. Effect of Temperature on Vapor-Phase Removal of Mercury across the ESP.

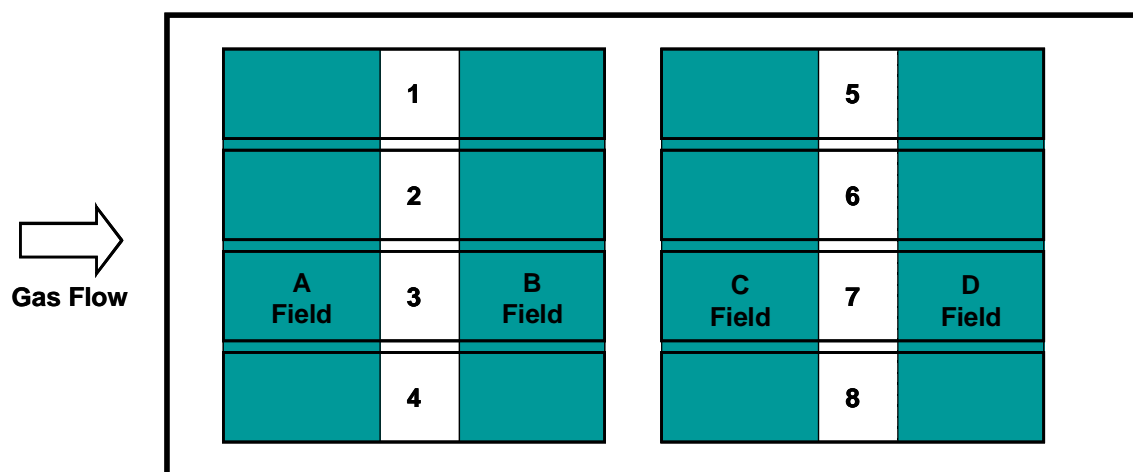


Figure 3-28. Diagram of Yates Unit 1 ESP

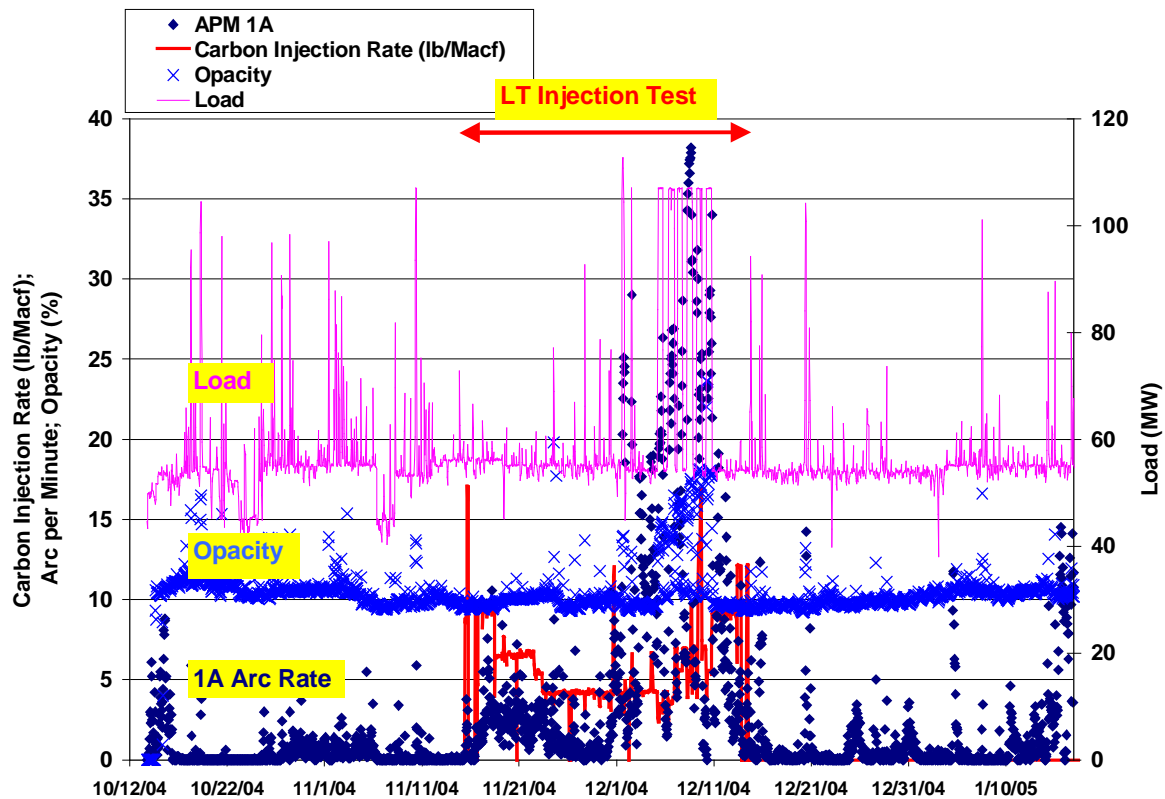


Figure 3-29. ESP, Load, and Carbon Injection Rate Data Previous, During, and Post Long-term Injection Test.

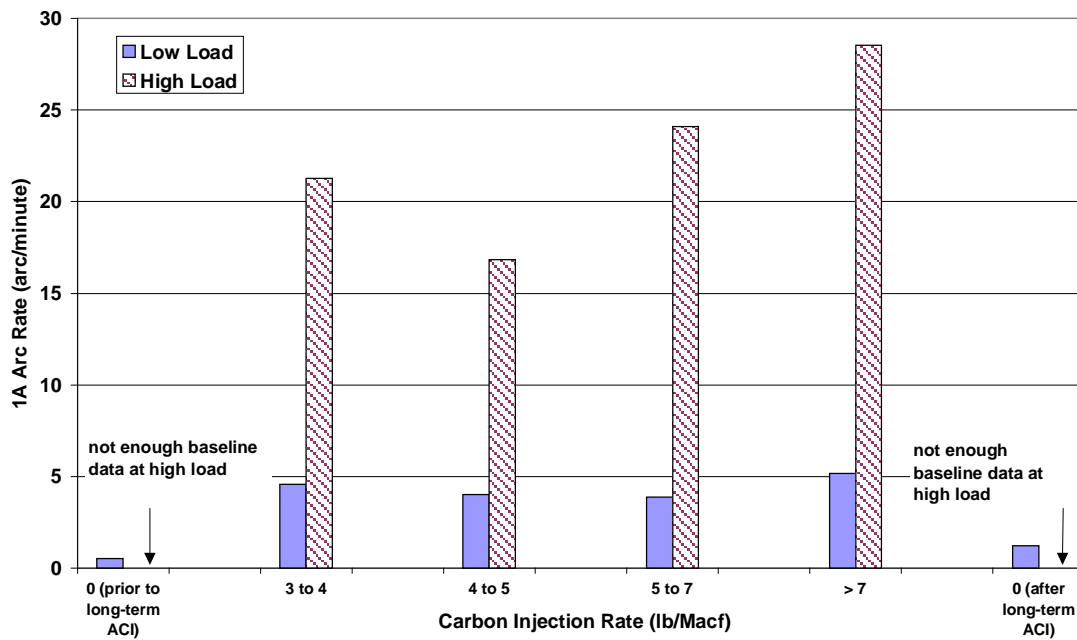


Figure 3-30. Average First Field Arc Rates at Various Carbon Injection Rates and Load Conditions

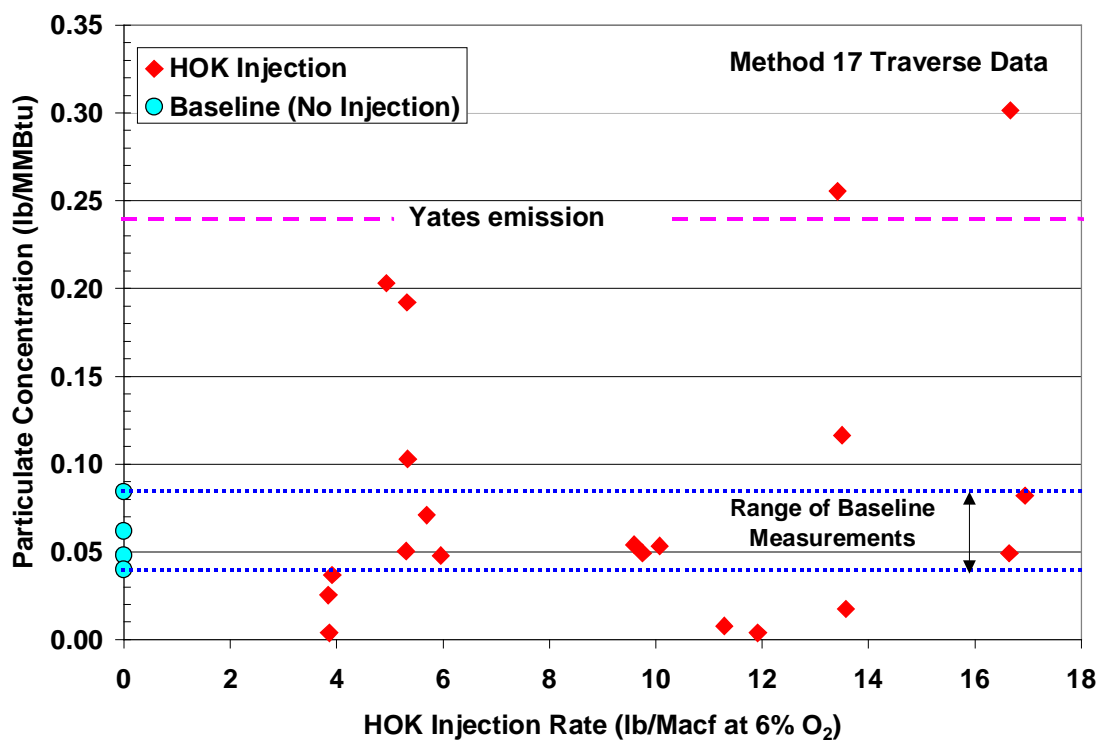


Figure 3-31. Method 17 Particulate Measurements versus Carbon Injection Rate.

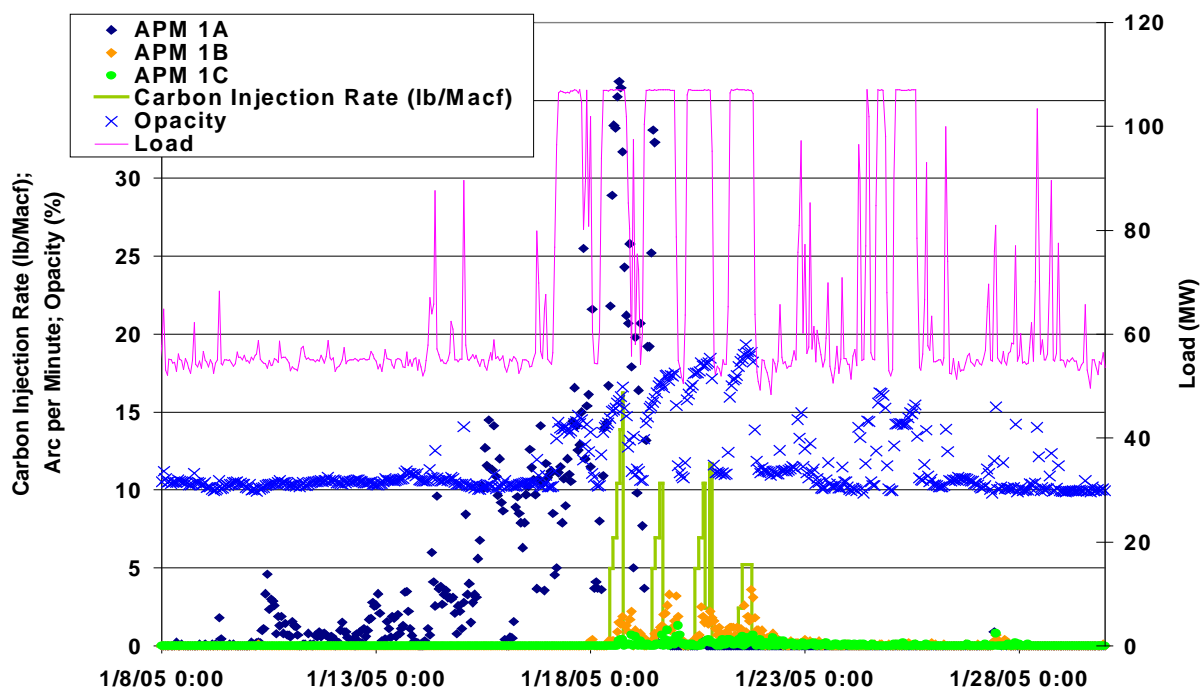


Figure 3-32. ESP, Load, and Carbon Injection Data Previous, During and Post January Parametric Testing.

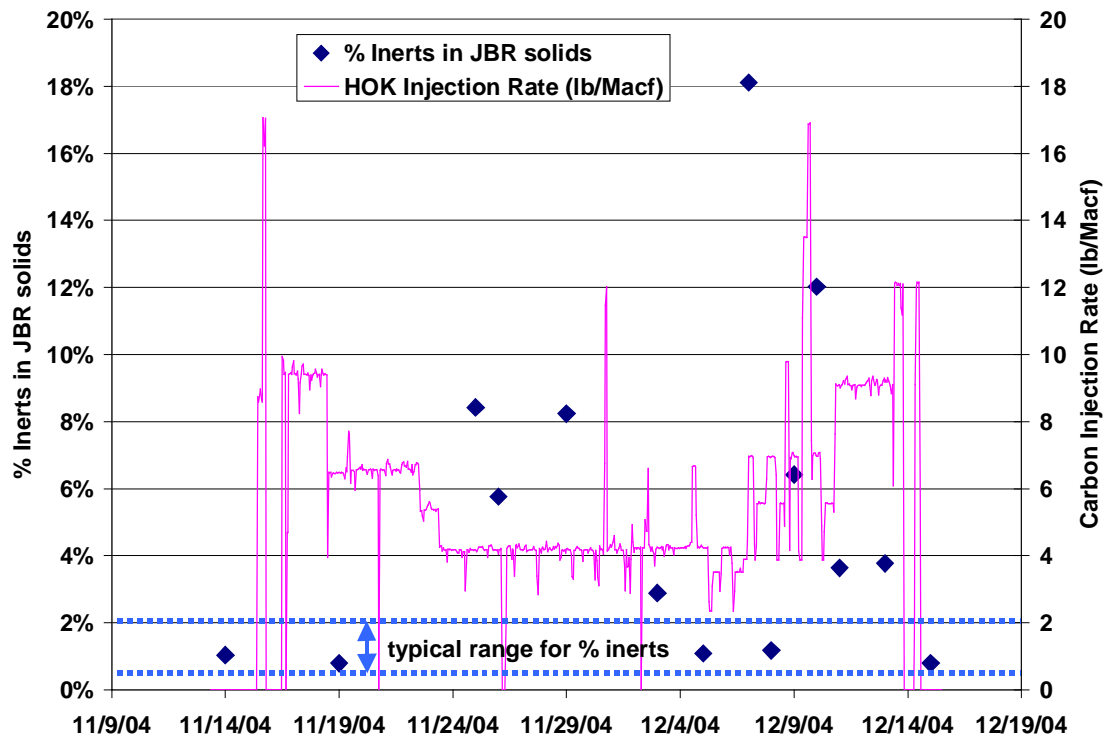


Figure 3-33 JBR Solids Inert Concentration during Long-term ACI test.

4.0 Conclusions and Recommendations

A sorbent injection test program was conducted on Plant Yates Unit 1, consisting of a parametric test program and a long-term test program. The purpose of the parametric test program was to compare the mercury removal efficiencies of various sorbents. The purpose of the long-term test program was to evaluate the variability in mercury removal performance over an extended period of time and to collect data about the balance of plant impacts of sorbent injection.

Six different sorbent were evaluated in the parametric test program: RWE Rheinbraun's Super HOK and coarse-ground HOK, Norit's Darco Hg and Darco Hg-LH, Ningxia Huahui activated carbon, and a Darco Hg/Miller PRB ash mixture. The mercury removal performance of all the tested sorbents appeared to plateau at an injection rate of about 6 to 9 lb/Mmacf. The maximum percent reduction in mercury achieved at the ESP outlet was approximately 45% during the original set of parametric tests conducted in Spring 2004. Carbon injection appeared to perform slightly better during the January 2005 parametric tests, with a maximum of 60% reduction in vapor phase mercury at the ESP outlet.

RWE Rheinbraun's Super HOK sorbent was selected for a thirty-day continuous injection test. During this test, flue gas mercury concentrations were monitored at the ESP inlet, ESP outlet, and the JBR outlet. Mercury removal across the ESP typically varied between 65 and 85%. The mercury removal across the ESP was somewhat higher during the long-term test, as compared to the parametric results. Carbon injection increased the arc rate of the ESP at low load. Evidence of carbon breakthrough from the ESP was evident in Method 17 filter samples and the JBR scrubber solids.

An economic analysis was performed to compare the relative costs of the different carbons tested in this test program. The results are currently under review by the project team and will be reported next quarter.

5.0 Activities Scheduled for Next Quarter

The Unit 1 and Unit 2 Site Reports will be finalized next quarter.

6.0 References

No references.

Appendix A

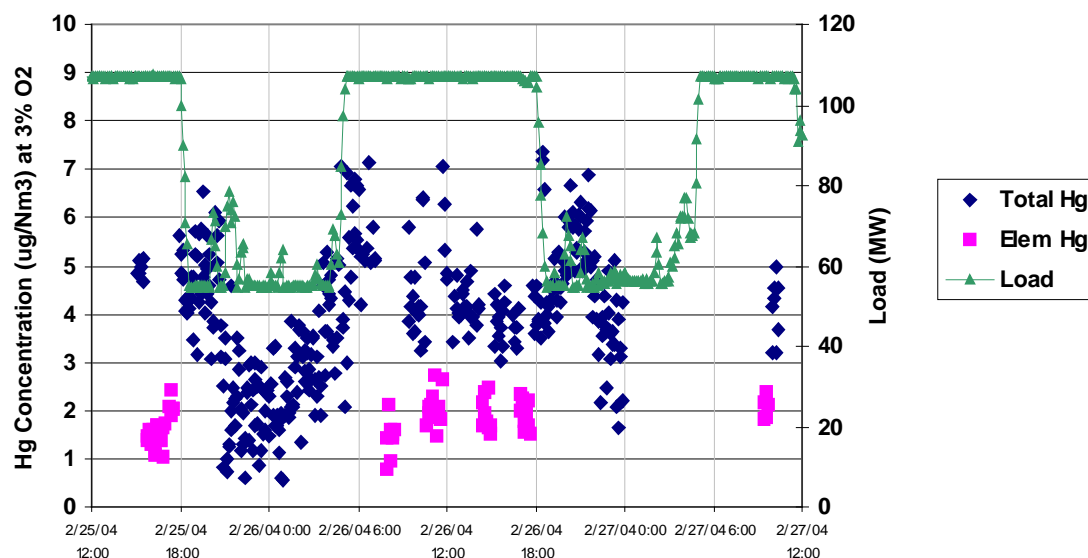


Figure
A-1. Unit 1 – SCEM Mercury Measurements at the ESP Inlet for the Baseline Characterization Test Periods

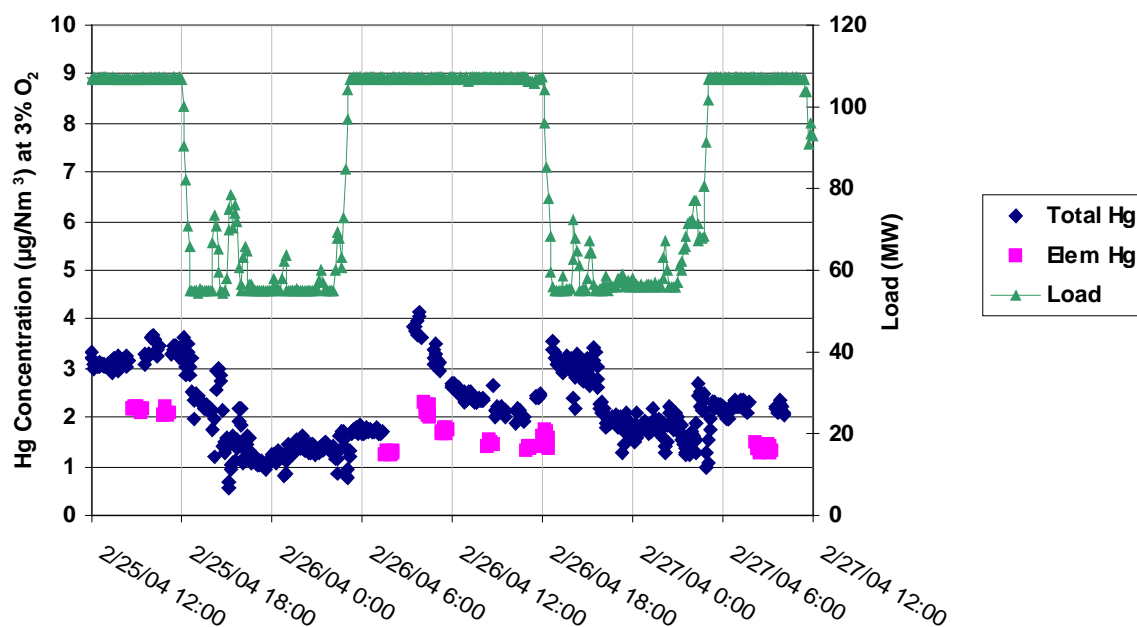


Figure A-2. Unit 1 – SCEM Mercury Measurements at the ESP Outlet for the Baseline Characterization Test Periods

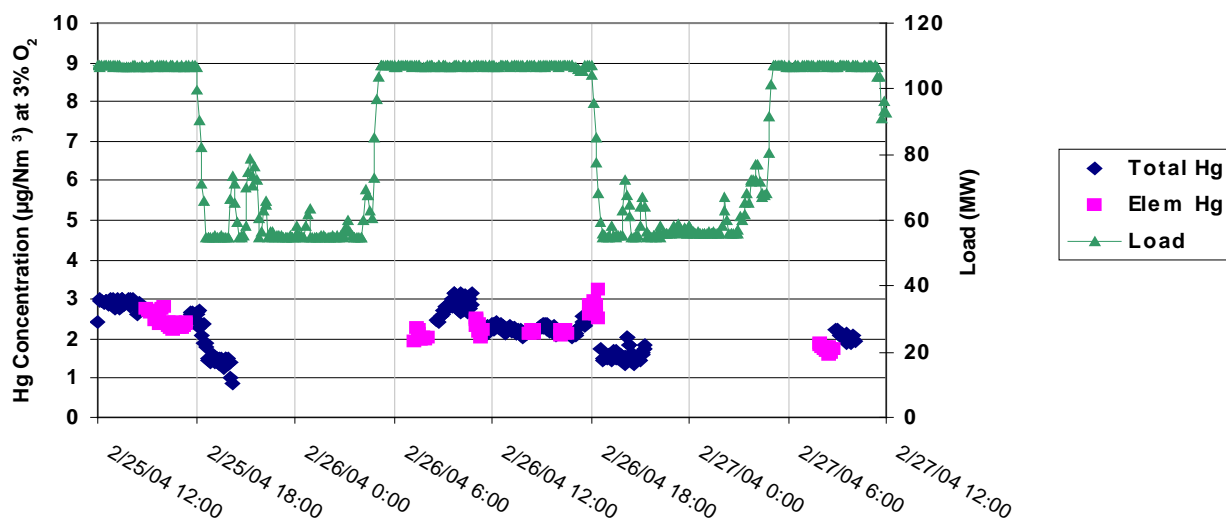


Figure A-3. Unit 1 – SCEM Mercury Measurements at the Stack for the Baseline Characterization Test Periods

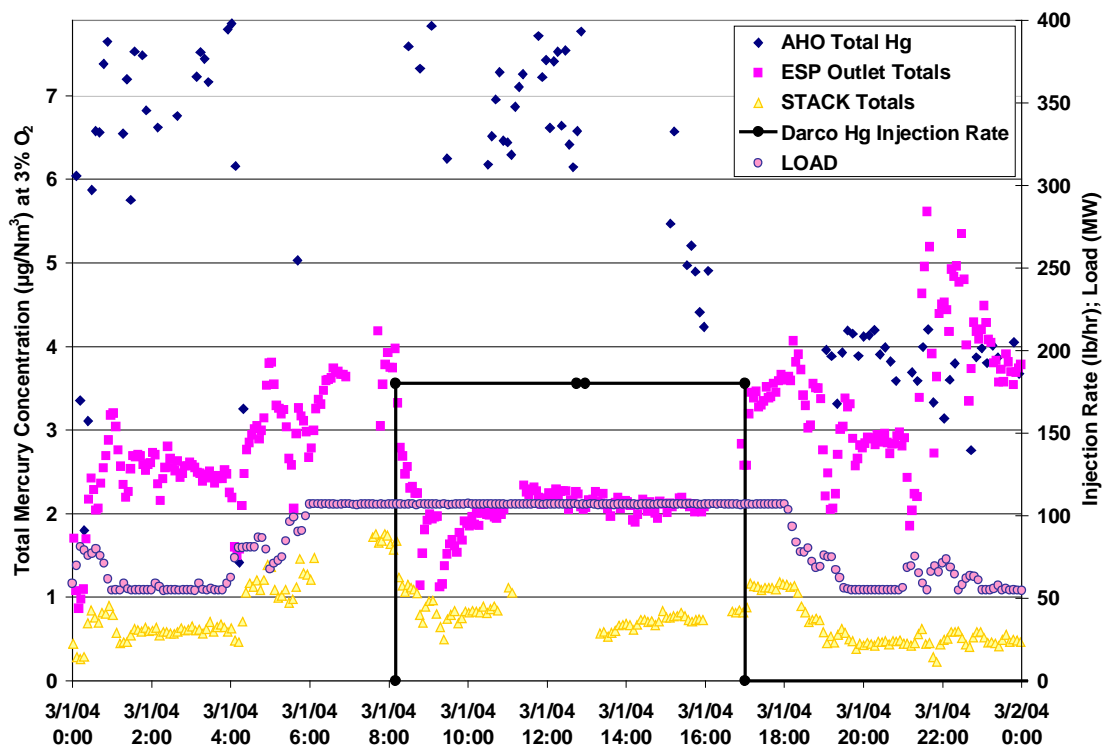


Figure A-4. Vapor Phase Mercury Concentrations measurements at Air Heater Outlet, ESP Outlet, and Stack during Day 1 of Darco Hg Injection Testing

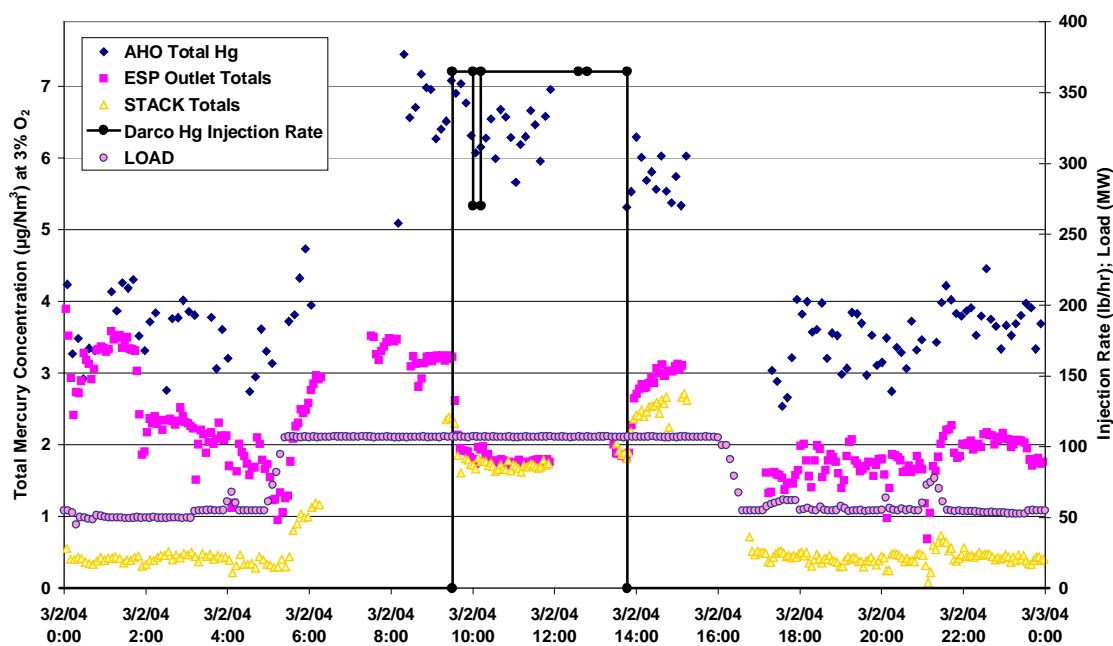


Figure A-5. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP Outlet, and Stack during Day 2 of Darco Hg Injection Testing

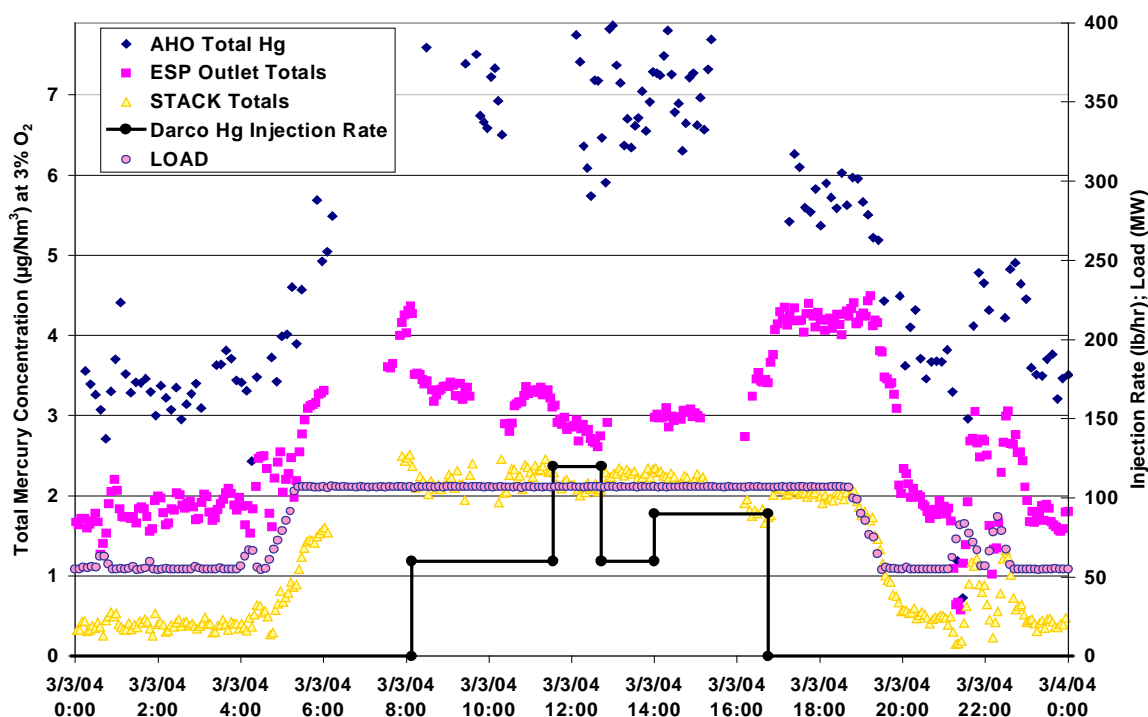


Figure A-6. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP Outlet, and Stack during Day 3 of Darco Hg Injection Testing

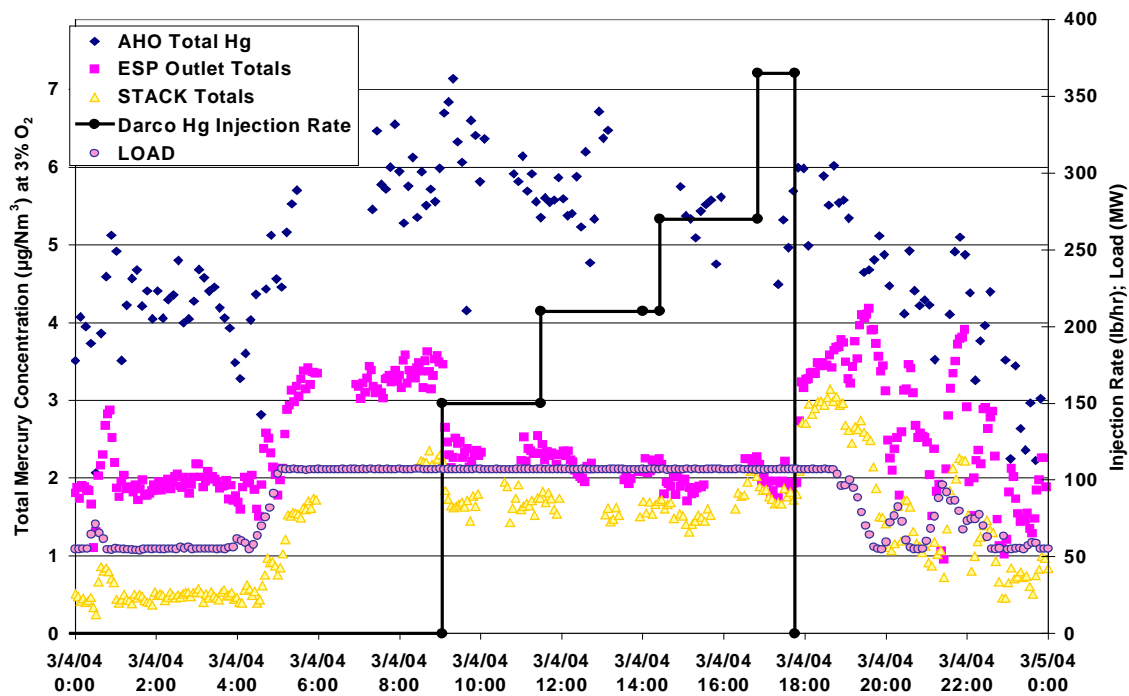


Figure A-7. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP Outlet, and Stack during Day 4 of Darco Hg Injection Testing

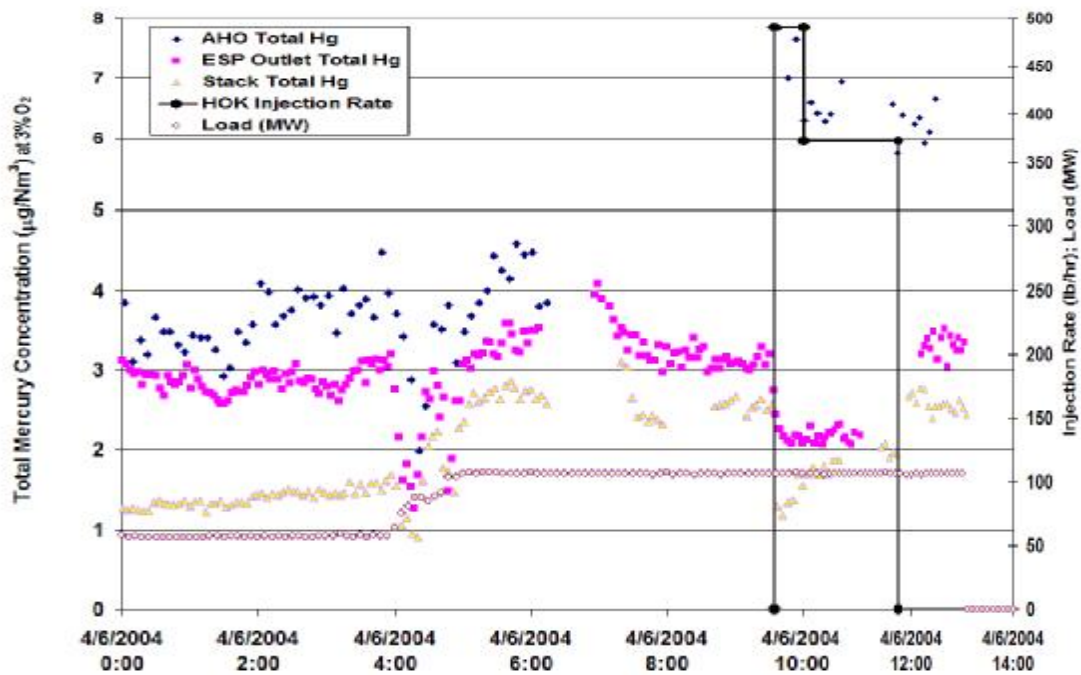


Figure A- 8. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP and Stack during Day 1 of Super HOK Injection Testing

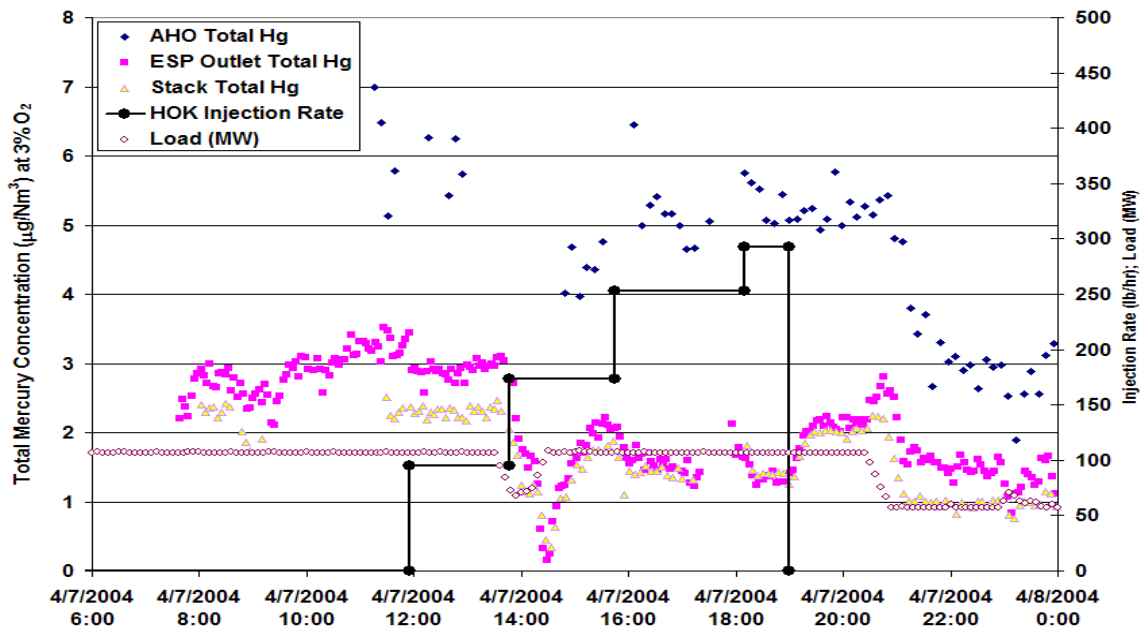


Figure A-9. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP Outlet, and Stack during Day 2 of Super HOK Injection Testing

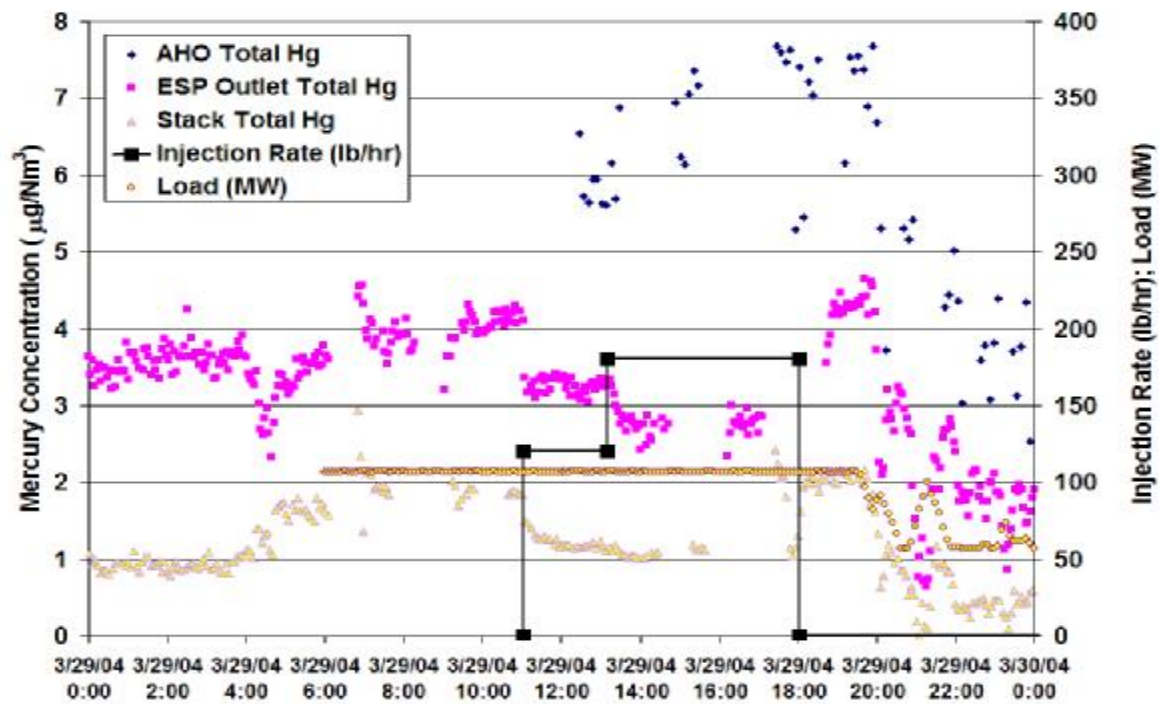


Figure A-10. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP Outlet, and Stack during Day 1 of NH Carbon Injection Testing

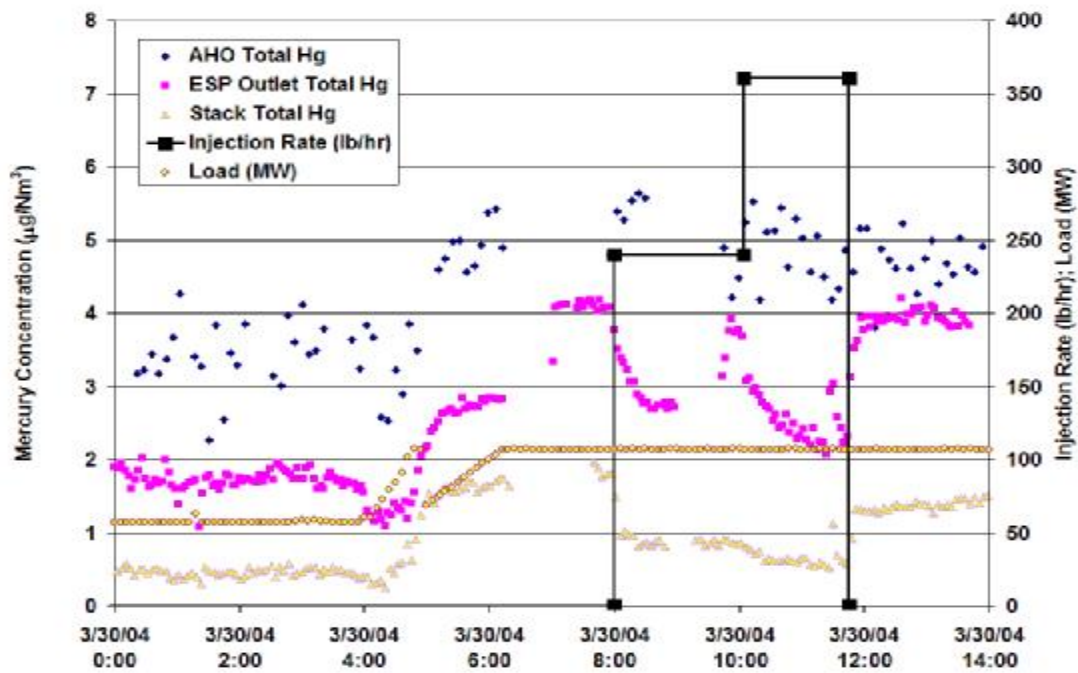


Figure A-11. Vapor Phase Mercury Concentrations measured at Air Heater Outlet, ESP Outlet, and Stack during Day 2 of NH Carbon Injection Testing

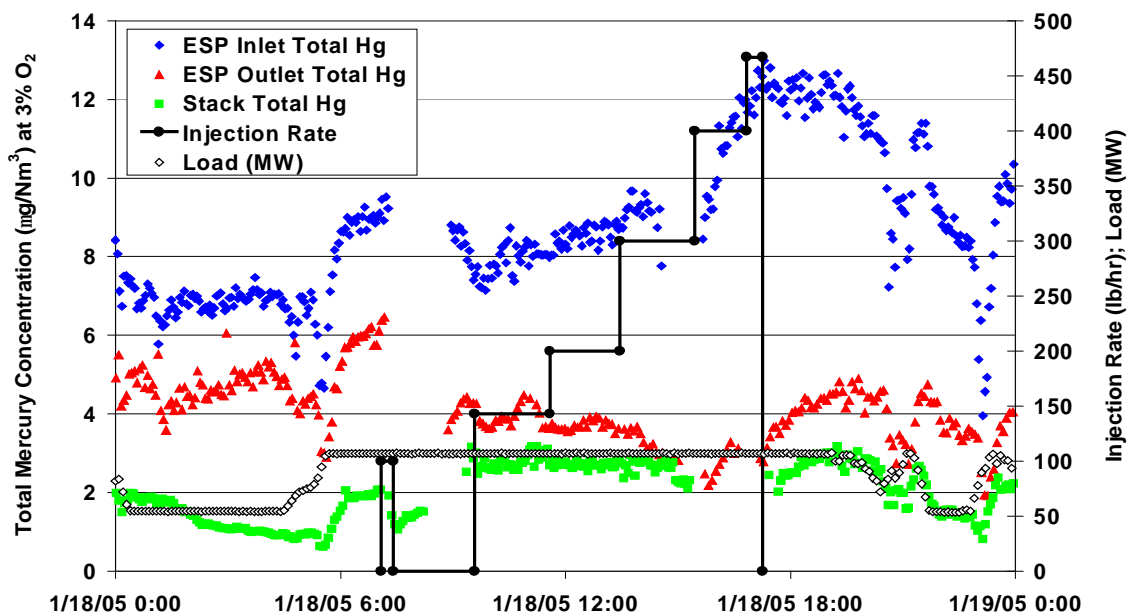


Figure A-12. Vapor-Phase Mercury Concentrations measured at ESP Inlet, ESP Outlet, and Stack during Coarse HOK Injection Testing

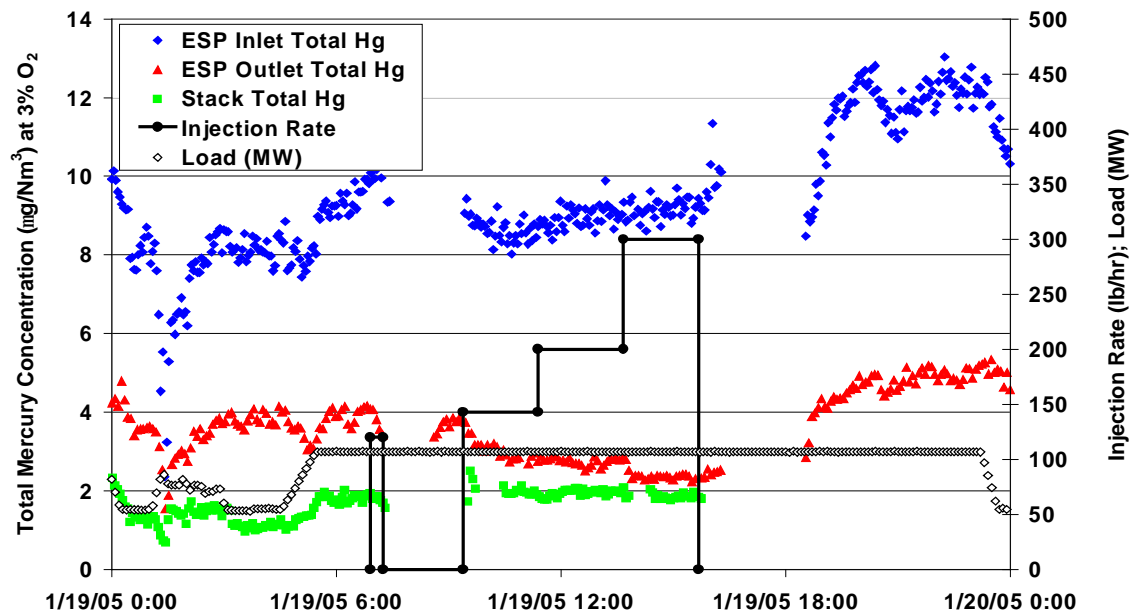


Figure A-13. Vapor-Phase Mercury Concentrations measured at ESP Inlet, ESP Outlet, and Stack during Darco HgTM-Miller Ash Blend Injection Testing

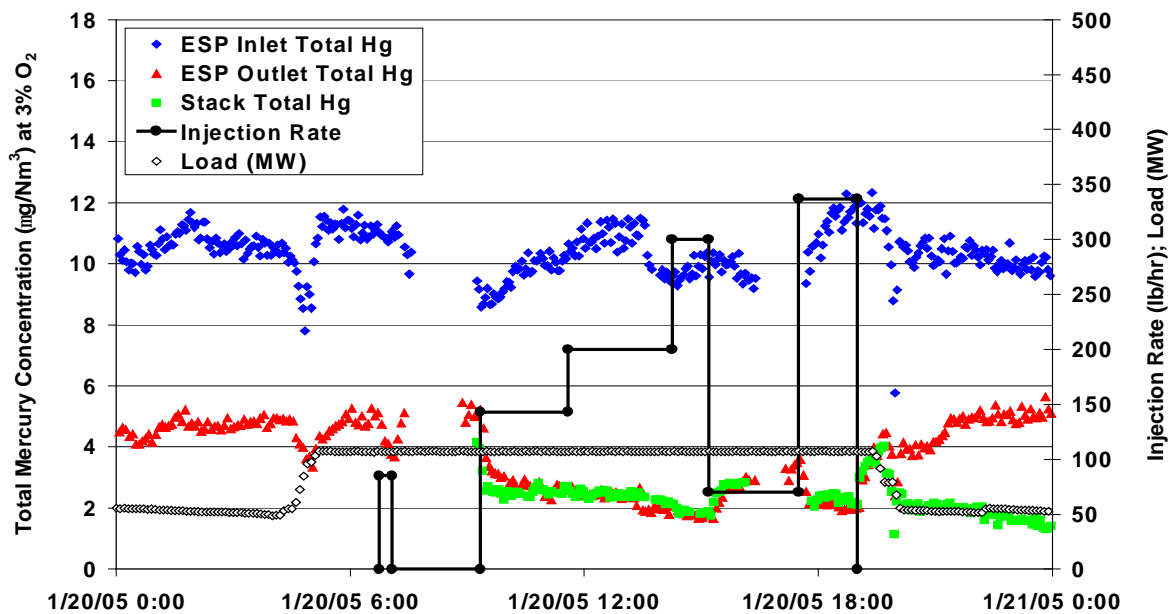


Figure A-14. Vapor-Phase Mercury Concentrations measured at ESP Inlet, ESP Outlet, and Stack during Darco Hg-LHTM Injection Testing

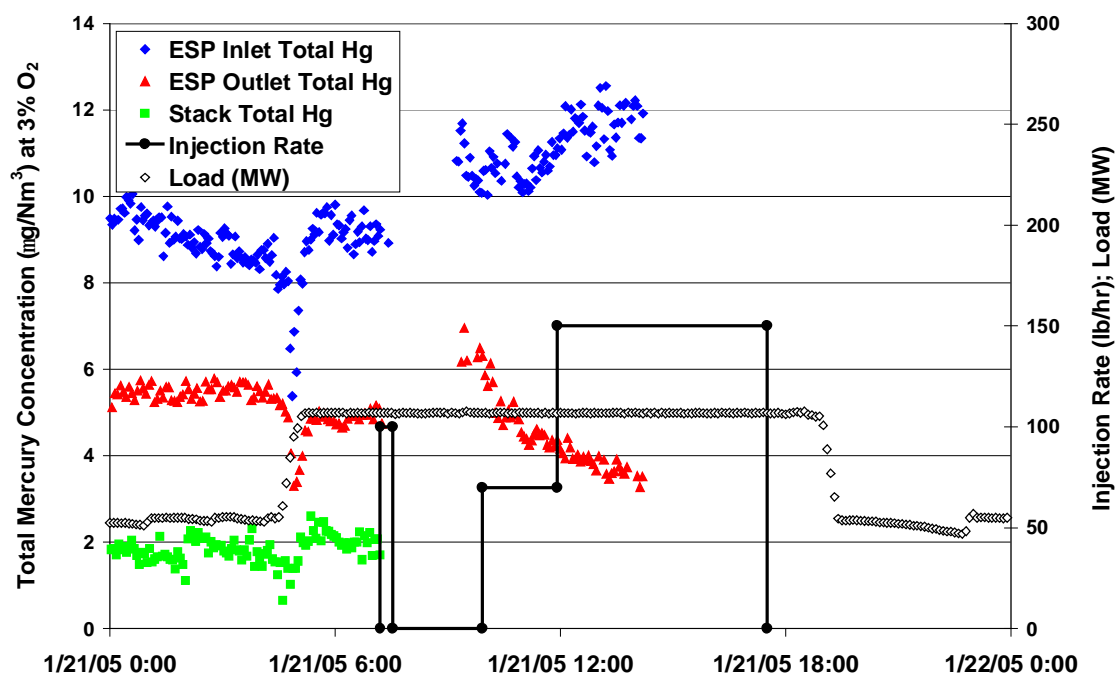


Figure A-15. Vapor-Phase Mercury Concentrations measured at ESP Inlet, ESP Outlet, and Stack during Darco HgTM Injection Testing